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METHODS OF STREAM PIRACY

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ABSTRACT

Two theories as to the method of the final act of stream capture and the growing tendency to assume that it always takes place underground are discussed. The factors governing capture are analyzed, and the possibilities of the two methods are compared. It is shown that, in soluble or pervious formations, subterranean transfer of water may take place and that capture will probably be by underground methods. In impervious formations, however, capture must usually be by surface methods. Therefore, the underground method is important in limestones, pervious sandstones, sand, and gravel; but in most igneous and metamorphic rocks and in shales and clays the final act of capture usually occurs on the surface.

INTRODUCTION

Although many instances of stream capture or piracy have been described, comparatively little has been written upon the methods by which it actually takes place. It is the purpose of this paper to discuss these methods and especially to analyze the two prevalent theories concerning the final act of piracy. According to one theory, the final act takes place suddenly by overflow of the upper stream into the valley of the lower or captor stream. According to the other, the capture occurs underground, and the water of the upper stream is practically all taken underground by the lower stream before the lower valley is actually cut back into the upper valley. The first theory is the older.

The earliest description of an actual case of capture by the under-

ground method which the present writer has found was by Lane,[1] who in 1898 described in some detail such a capture in porous sandstone and referred to one in sand. Since the publication of Lane's article, there has been an increasing tendency to consider the method therein described almost to the exclusion of the other. This was exemplified in an article by Johnson[2] nine years later in which he referred to the article by Lane, gave the impression that stream capture would usually take place in this manner, and used the underground theory to explain some features of an actual case of stream capture. It does not appear, however, that he determined that the conditions were especially suitable for underground capture but merely assumed that it would take place in that manner, though the geological conditions were entirely different from those described by Lane. Cotton[3] states: "By the time the stage of imminent capture is reached the headward erosion of the stream which is about to make the capture is hastened by an augmentation of its volume due to seepage of ground water leaking down through the bed of the threatened river." This statement gives the impression that underground transfer of water in considerable quantity always plays an important part in stream capture. Recently the assumption that stream capture always takes place by the underground method has been used by Mackin[4] to prove that capture did not take place in the specific cases he was considering.

On account of these and other unsupported statements on the subject, it has seemed desirable to analyze the conditions which would permit of each method of capture and to show which method is most likely to occur under different conditions.

TYPES OF STREAM CAPTURE

Piracy may involve two surface streams, two subterranean streams, or a surface and a subterranean stream. This paper will be

[1] Alfred C. Lane, "A Note on a Method of Stream Capture," *Geol. Soc. Amer. Bull. 10* (1898), pp. 12–14.

[2] D. W. Johnson, "Drainage Modifications in the Tallulah District," *Proc. Boston Soc. Nat. Hist.*, Vol. XXXIII, No. 4 (1907), pp. 244–45.

[3] C. A. Cotton, *Geomorphology of New Zealand* (Wellington, New Zealand, 1922), p. 78.

[4] J. Hoover Mackin, "Evolution of Hudson, Delaware, Susquehanna Drainage, *Amer. Jour. Sci.*, Vol. XXVI, No. 153 (September, 1933), p. 326.

limited to the capture of surface streams by surface streams or by subterranean tributaries of surface streams. There are three distinct types: capture by headward erosion; planation capture; and capture by underground methods. The first is probably the more common of the two surface types, but many cases of the second type are known. The final act of both these types may occur underground if conditions are suitable, and this will be discussed at length later.

There are known cases of capture of a surface stream by a subterranean stream in which capture by surface methods would probably not have ocurred for a very long time, if at all. These truly subterranean captures occur practically always in soluble rocks and should be differentiated from captures by surface streams, in which the final act takes place underground, but which would not have occurred if surface erosion had not prepared the stage.

Capture by headward erosion.—Wherever two adjacent streams are at markedly different levels and the tributaries of the lower are working back toward the upper stream, the stage is set for capture of the upper stream. Given sufficient time without change of conditions, the lower stream will eventually gnaw back the head of its valley until it has cut through the divide and captured the upper stream. In the Catskills, Kaaterskill and Plaaterskill creeks have captured tributaries of Schoharie Creek and afford typical examples of capture by headward erosion.[5] Hominy Creek in North Carolina offers a good example of actual capture and also of imminent capture. The head of Hominy Creek has already captured a tributary of Pigeon River and is now working back at a lower level close to Pigeon River near Canton.[6] Although the head of the would-be pirate is only about two-thirds of a mile from the prospective captive, and the rock is deeply weathered schist with the strike leading from Hominy Creek toward Pigeon River, there is no evidence of any seepage from the river to the creek. The water in the creek seeps from the hillsides as can be seen in a railroad cut through the divide.

[5] Nelson H. Darton, "Examples of Stream Robbing in the Catskill Mountains," *Geol. Soc. Amer. Bull.* 7 (1896), pp. 505–7; R. D. Salisbury, and W. W. Atwood, "Interpretation of Topographic Maps," *U.S. Geol. Surv. Prof. Paper 69*, pp. 49–50.

[6] Hunter L. Harris, "A New Instance of Stream Capture," *Proc. Boston Soc. Nat. Hist.*, Vol. XXVI, pp. 27–29; also *Sci.*, Vol. XXII (July 21, 1893), pp. 36–37; Frank J. Wright, "Stream Piracy near Asheville, North Carolina," *Jour. Sci. Lab. Denison Univ.*, Vol. XXIV (1930), pp. 401–6.

Planation capture.—Planation capture is due to the lateral cutting of one stream into the valley of another stream and does not require appreciable difference of level. This type of capture is also known as intercision, and many examples have been described in the literature.[7]

Subterranean capture of surface streams.—The subterranean type of stream capture is important in soluble rocks, and many examples have been described.[8] In most of these cases the streams were a considerable distance apart, the entire capture took place underground, and the work was largely done by the diverted stream or captive. There is an especially good sample of subterranean capture near Bloomington, Indiana, where Indian Creek flows on a gentle grade at a high level, but Clear Creek on the east and Richland Creek on the west flow at much lower levels and have captured about 15 square miles of the headwaters of Indian Creek. The water of the captured part of Indian Creek disappears in large sinks and comes out again in springs miles away in the valleys of Clear Creek and Richland Creek.[9] Capture might not have occurred by surface methods, at least not for a very long time and the valleys are not yet connected. These cases of subterranean capture should be differentiated from stream captures in which most of the work is done by surface agencies but in which the final act of transfer of water from the upper to the lower stream may take place underground. The underground portion of such captures is short and unimportant compared with these cases of true subterranean capture.

Subterranean piracy in which the underground portion is important and the distance considerable is practically confined to areas of

[7] Clyde A. Malott, "Planation Stream Piracy," *Proc. Indiana Acad. Sci.* (1920), pp. 149–260; Salisbury and Atwood, *op. cit.*, p. 51; Isaiah Bowman, "A Typical Case of Stream Capture in Michigan," *Jour. Geol.*, Vol. XIII (1904), pp. 326–35.

[8] C. L. Dake, and Josiah Bridge, "Subterranean Stream Piracy in the Ozarks," *Univ. Mo. School of Mines and Metallurgy Bull.* 7, No. 1 (November, 1923), pp. 3–14; E. Fournier, "Les Phénomènes de capture des cours d'eau superficiels par les cours d'eau souterrains, dans les régions calcairs," *Comptes rendus, Académie des Sciences* (December 2, 1901), pp. 961–69.

[9] J. W. Beede, "The Cycle of Subterranean Drainage as Illustrated in the Bloomington, Indiana, Quadrangle," *Proc. Indiana Acad. Sci.* (1910), pp. 81–111; Clyde A. Malott, "A Subterranean Cut-off and Other Subterranean Phenomena along Indian Creek, Lawrence County, Indiana," *Proc. Indiana Acad. Sci.* (1921), pp. 203–10.

soluble rocks, since water seeping for long distances through relatively insoluble formations from an upper to a lower stream would have little effect upon the rocks. Subterranean capture may eventually develop an open valley, and evidence as to the type of piracy may be largely obscured, or destroyed.

METHODS OF STREAM CAPTURE

Surface methods of capture.—Erosion is gnawing back at the headwaters of every stream, the rate depending upon the character of the formations, the declivity of the ground, the rainfall and other climatic conditions, the nature of protecting vegetation, and other factors. Weathering breaks the rocks into fragments and reduces them to soil. Rainwash, sheet floods in arid regions,[10] and unconcentrated wash in humid regions[11] carry the soil into streams. On steep slopes fragments roll down, soil creeps down the slope, and landslides move large volumes of material in a short time. In high latitudes or at high altitude solifluction may be important.[12] The head of any valley is thus cut back at a greater or lesser rate, the relative importance of these different processes varying with conditions.

The ability of a stream to capture another stream is dependent upon its ability to maintain its channel at a lower level than that of the upper stream. The principal factors governing the rate of the mechanical erosion of the channel are the quantity of water, its velocity, the character and quantity of the tools available for it to work with, and the nature and structure of the formation over which it flows.

The erosive power of a stream increases greatly with the velocity. The statement is current that the competency of a stream—that is, the maximum size of a particle which a stream can move—varies

[10] W. J. McGee, "Sheet Flood Erosion," *Geol. Soc. Amer. Bull. 8* (1891), pp. 87–112; John L. Rich, "Origin and Evolution of Rock Fans and Pediments," *Geol. Soc. Amer. Bull. 46* (1935), pp. 999–1024.

[11] N. M. Fenneman, "Some Features of Erosion by Unconcentrated Wash," *Jour. Geol.*, Vol. VI, pp. 746–54.

[12] J. G. Anderson, "Solifluction, a Component of Subaerial Denudation," *Jour. Geol.*, Vol. XIV (1906), pp. 91–112; H. M. Eakin, "The Yukon-Koyukuk Region, Alaska," *U.S. Geol. Surv. Bull. 631* (1916), pp. 76–82.

with the sixth power of the velocity.[13] The capacity of a stream, which is the total amount of sediment which it can transport, has been stated to vary with the third power, the fourth power,[14] the fifth power,[15] and the sixth power[16] of the velocity.

It has been frequently stated that the abrasive power of a stream varies with the square of the velocity.[17] But other investigators state that it varies with the third power of the velocity,[18] which means that per unit area the power of the stream to abrade the rock varies as the cube of the velocity if the stream continues to carry the same number of particles of the same size for each unit volume of water. In the case of increased velocities due to increased volume the abrasive power would increase more rapidly, since with increase of volume there is increase of channel, a greater area is subject to abrasion, and there may be an increase of tools carried by the stream. For channels of triangular cross section the total abrasion would vary as the sixth power of the velocity.[19] The exact rate of increase will depend upon local conditions such as the quantity and size of the debris available, but it is clear that the abrasive power must increase at least as the cube and probably at a much higher rate. These facts illustrate the very great advantage possessed by the stream with a steeper channel and, therefore, higher velocity.

The great erosive power of floods is due not only to the increased flow but even more to the greatly increased velocity which ac-

[13] Sir John Leslie, *Elements of Natural Philosophy* (Edinburgh, 1829), Vol. I, pp. 426–27; Wilfrid Airy, *Proc. Inst. Civil Engineers*, Vol. LXXXII (1885), pp. 25–26, with expansion by Henry Law, pp. 29–31; William Hopkins, "On the Transport of Erratic Blocks," *Trans. Cambridge Philos. Soc.*, Vol. VIII (1844), pp. 225–33; W. W. Rubey, "Settling Velocities of Gravel, Sand and Silt Particles," *Amer. Jour. Sci.*, Vol. XXV (1933), pp. 325–38.

[14] Grove Karl Gilbert, "The Transportation of Debris by Running Water," *U.S. Geol. Surv. Prof. Paper 86* (1914), p. 11.

[15] G. F. Deacon, "Discussion on Training of Rivers," *Proc. Inst. Civil Engineers*, Vol. CXVIII (1894), pp. 93–96.

[16] J. S. Owens, "The Settlement and Transport of Sand in Water," *Engineering*, Vol. XCIV (1912), pp. 862–64.

[17] Amadeus W. Grabau, *Text Book of Geology* (Boston, 1920), Vol. I, pp. 412–13.

[18] Rubey, oral communication, May, 1935; E. C. Andrews, "Corrosion by Gravity Streams with Applications to the Ice Flood Hypothesis," *Jour. and Proc. Royal Soc. New South Wales*, Vol. III (1929), pp. 327–28.

[19] Rubey, oral communication, May, 1935.

companies increased flow. Flood discharges 100–1,000 times the normal flow have been recorded,[20] and flood velocities 10–20 times as great as low-water velocities are known.[21] These facts make understandable the long-recognized tremendous erosive power of floods.[22]

With these facts in mind the imagined impossibility of the tiny headwater stream of a pirate gnawing back through a divide of hard rocks disappears. If one views such a divide during a prolonged downpour, when torrents of muddy water are rushing from every hillside, and the now swollen stream is rolling boulders down its bed, and new gullies are forming before one's eyes, it does not seem difficult for the stream to cut back through the divide. One such flood clears much of the debris out of the valley bottom, pries out loosened blocks, and wears the ledges, thus deepening the valley. The rainwash sweeps away loose debris and actively erodes the soil of the divide. In the periods between floods, weathering attacks the rocks and provides more soil and debris at the expense of the divide for the next flood to sweep away. Thus the attack on the divide continues until an apparently impotent little brook has cut through into the upper valley and captured the headwaters of the upper stream by surface methods.

If the formations are relatively impervious, which is often the case, the final act of capture will occur on the surface when the lower stream has cut back and reduced the divide below the extreme flood level of the upper stream. Even if the overflow is slight, it will remove the soil, deepen the overflow channel, and increase the quantity of overflow. If the rocks are resistant and not deeply weathered, the flood may subside without having made a permanent channel into the lower stream; but the overflow channel will be lower and

[20] Morgan Creek near Chapel Hill, North Carolina, has had a recorded flood flow 923 times as great as its mean recorded flow (*U.S. Geol. Surv. Water Supply Papers 582, 602, 622, 642, 662, 682, 697, 712, 727*). The flood of November, 1927, on the White River near Hartford, Vermont, was 123 times as great as the mean flow (U.S. Geol. Surv. stream records). During the recent floods in southern New York flows 1,200 times as great as normal discharge were recorded (*Eng. News Record*, Vol. XV [1935], pp. 161–62).

[21] A twenty-one-fold increase of velocity was recorded at the U.S. Geol. Surv. gaging station on the Connecticut River at Montague City, Massachusetts.

[22] Sir Archibald Geikie, *Text Book of Geology* (New York, 1903), p. 493.

available for a flood of lesser height, which will further enlarge and deepen the channel until a permanent flow takes place into the pirate stream, and finally the pirate obtains the entire flow of the upper or captive stream.

In the case of unconsolidated formations, however, the first flood to overtop the divide will probably complete the capture, often with catastrophic results. Such conditions were demonstrated during the Vermont flood of 1927.[23] At Cavendish, Vermont, Black River went around a bend passing through a rocky gorge and falling 154 feet. The neck of this bend was, however, composed of sand and gravel, and there was a low saddle from which a gully led to the stream below the falls. During the flood the river overflowed the divide in the saddle and cut a gorge about 30 feet deep in a few hours. Its cutting was then checked by a ledge of bed rock, and permanent diversion of the stream was prevented by man. Somewhat similar conditions exist whenever a river in flood cuts off a meander.

When two adjacent streams at different levels are separated by a pervious formation, the lower stream will tend to draw off part of the ground-water supply of the upper stream, thus decreasing the flow of the upper stream, increasing the flow of the lower stream, and thereby tending to increase its ability to erode. Unless, however, this underground leakage takes the major part of the flow of the upper stream it is relatively unimportant in completing capture except in the case of soluble rocks, or of very pervious formations or of formations which are weakened by the flow of water through them.

If, for example, the flow of the headwaters of the would-be pirate were doubled by seepage, its velocity would be somewhat increased, much less than doubled, and its transporting and abrasive powers would be considerably increased. This increase of erosion from seepage would be moderate and nearly constant throughout the year, and, since this seepage is assumed to be flowing through rocks not affected by water, the amount of seepage will not increase and even at its outlet the seepage will not cause sapping or slides. Therefore, it will not be effective in pushing back the divide but will merely

[23] E. C. Jacobs, "Flood Erosion at Cavendish, Vermont," *Sci.*, Vol. LXVI (1927), pp. 653–54; Irving B. Crosby, "Geology in the Making," *Jour. Boston Soc. Civil Engineers*, Vol. XV, No. 1 (1928), pp. 33–35.

tend to deepen the channel. Every year, however, there will be periods of high water with one or more floods which will in one day cause many times the erosion in the stream channel that doubling the stream by seepage could do in a year. In addition, heavy downpours do effective work on the divide in sweeping away the debris and soil formed by weathering, thus hastening piracy. Even though there is considerable seepage it will have little effect on the height of floods in the upper stream, and finally the divide will be overtopped.

Aggradation by the stream about to be captured sometimes plays an important part in the final act of capture. This is demonstrated in Pinkham Notch, New Hampshire,[24] where Ellis River, a rapid southward-flowing tributary of the Saco, has beheaded the East Branch of the Peabody River, which flows north into the Androscoggin. Cuttler River, formerly one of the headwater tributaries of the Peabody River, descends steeply into the flat saddle of Pinkham Notch and deposits its load of gravel, building up a fan. The stream has swung from side to side of this fan, repeatedly changing its outlet from the Peabody to the Ellis River and vice versa. The first connection between the Cuttler River and the pirate Ellis River was caused, earlier than would otherwise have happened, by aggradation on the fan of Cuttler River. For many years Cuttler River has been tributary to the Ellis River, but a flood channel still occasionally carries water into the Peabody River. Although much water seeps through the gravels of the fan and some of this seepage is tributary to the Peabody River, it has little or no effect upon the completion of the capture. The gravels are so coarse that there is no possibility of the occurrence of "piping." Aggradation is probably often effective in turning the upper stream into the pirate sooner than would otherwise be the case.

In the case of capture by planation the most important process is the lateral planation of one or both of the streams involved, though rainwash, slides, solifluction, and, in fact, all the processes which are active in headward erosion may take part here to greater or less extent.

[24] Crosby, "The Physiographic History of Pinkham Notch," *Appalachia*, Vol. XV, No. 4 (April, 1924), pp. 462–65.

Underground methods of capture in soluble rocks.—In soluble rocks the underground methods of capture are very important, and since limestone, the commonest soluble rock, is the surface rock of large areas, captures completed by the underground method are numerous. Most limestones are dense, and water can pass through them only in cracks; but some soluble rocks are pervious, and in such cases underground flow may work very rapidly. A demonstration of this was given by the failure of the St. Francis dam in California.[25] The rock in question was a conglomerate cemented by clay and gypsum. The conglomerate became saturated, the gypsum dissolved, and finally water broke through in great volume. The final act of stream capture may occur in similar manner when the conditions are similar.

If the rock is intersected by a well-developed system of regular joints, a regular system of caves will be formed, and the capture of the upper stream will be completed underground although their valleys may not be connected for a long time. If, however, the rock does not have a well-developed joint system, solution channels may not develop and the underground method may not be so effective in promoting capture. Therefore, although capture in soluble rocks is usually by the underground method, it is not certain that it always occurs that way, since a well-developed system of interconnecting joints is necessary for the development of subterranean drainage systems and of subterranean stream capture, and some limestones do not have the necessary well-developed joints.

Underground methods in insoluble, impervious rocks.—The insoluble rocks may be subdivided into the impervious and the pervious. Water passing through the cracks of impervious rocks has little or no effect upon them, and, if the water carries silt, the flow may even be reduced. Therefore, since the water passages are not enlarged, this seepage cannot directly bring about capture unless the rocks are extremely leaky as might be the case if they were intersected by a fault, containing gouge which could be removed by the flow of water. In rocks with the usual degree of jointing the amount of seepage would be relatively small and would usually take only a very small part of the ground water of the upper stream. The seep-

[25] R. L. Ransome, "Geology of the St. Francis Dam Site," *Econ. Geol.*, Vol. XXIII, No. 5 (1928), pp. 553–63.

age would, of course, increase the flow of the lower stream, but, as has been shown, this is relatively unimportant in lowering the divide and completing capture. In insoluble, impervious rocks it is probable that in most cases the effect of the slight seepage which occurs is practically negligible.

Most joint cracks become very tight a short distance beneath the surface and carry very little water, as can be seen in quarries, mines, and tunnels. In cases where a large subterranean flow has been encountered in underground operations, a fault or a zone of close jointing is usually responsible.[26] In many cases of capture the upper stream is relatively sluggish, and, if its channel is floored with clay or silt, the fine material will effectively reduce the amount of water which can enter cracks in the rock.

Waterfalls present a condition somewhat similar to that which exists when stream capture is imminent. In the case of a fall over a cliff of bare rock, water from the stream above the fall has an opportunity to enter cracks in the rock in the bed of the stream, flow through the rock, thus by-passing the fall, and come out as springs in the valley below the fall. Part of this hypothetical seepage back of the fall might come out in the channel of the stream and be concealed, but it is highly probable that at least part of it would come out along the banks where it would be visible at low water. In many cases the conditions are excellent for observing such seepage. The writer has failed to find any evidence that an appreciable amount of water by-passes falls in this manner in massive, insoluble rocks. In some cases a very slight seepage from joint cracks at the foot of falls has been seen, but it is probable that this comes from the general body of ground water and not from the stream or from the valley above the fall. The failure of water to by-pass waterfalls through insoluble rocks is demonstrated by the fact that no appreciable amount of water by-passes any of the major waterfalls in the Yosemite region.[27]

[26] "Driving the Tanna Railway Tunnel in Japan," *Eng. News Record*, Vol. CIV, No. 9 (February 27, 1930), pp. 367–72; Takewata, "Holing through a Six Mile Tunnel on the Japanese Railways," *Eng. News Record*, Vol. CIV, No. 26 (June 26, 1930), p. 1062; T. S. Lovering, "Geology of the Moffat Tunnel, Colorado," *Trans. Amer. Inst. Mech. Eng.*, Vol. LXXVI (1928), pp. 337–46.

[27] François E. Matthes, written communication, December, 1934.

In the case of soluble rocks it is known that such by-passing of waterfalls takes place and that the cracks become enlarged sometimes to the extent of taking the entire flow of the stream and forming a natural bridge. The contrast of conditions in insoluble and soluble rocks is thus demonstrated by waterfalls.

Since by-passing of a fall in this manner is rarely if ever important in the case of impervious, insoluble rocks, it is improbable that seepage of water through the cracks of insoluble rocks is an important factor in the final act of stream capture except where the rocks are fractured much more than is ordinarily the case.

Underground methods in insoluble pervious rocks.—The conditions in pervious rocks are different from those in dense rocks. The great majority of captures by the underground method outside of limestone regions occurs in pervious rocks. Sandstone is the principal consolidated rock in this class, and an example in northern Michigan has been described by Lane, where the lower of two adjacent streams has drawn off through porous sandstone all the water of the higher stream[28] and has caused its capture without any surface connection between the two streams or their valleys. Where the water came out in the valley of the lower stream, it had softened the sandstone, and slides had occurred. In this case the upper stream was directly and effectively aiding in its own capture, since, in addition to increasing the volume and erosive ability of the lower stream, it was weakening the sandstone through which it passed. A most important factor in piracy in sandstones is the lowering of the ground-water table by the pirate, thus depriving the upper stream of part or all of its ground-water supply. This is undoubtedly a common occurrence, but cases where the sandstone is softened and the connection of the valleys is hastened by slides as described by Lane are probably rather rare. Seepage may increase the flow of the lower stream and thus hasten capture, and yet the final act may still be by overflow of the upper stream in time of flood.

Underground methods in unconsolidated formations.—Obviously, if the material is impervious, no water can pass through it, and underground methods cannot take any part in stream capture. This is certainly the case with massive deposits of clay or clayey silt and with

[28] *Op. cit.*, pp. 12–15.

most boulder clays. With deposits of interlaminated clay and sandy silt the case may, however, be different. If the capture of one stream by another in such a deposit is imminent, the water of the upper stream may contribute in a very important manner to its own capture by saturating the laminated clay and silt until its condition becomes unstable, and a silt flow results. Silt flows of large size are not uncommon, and several examples have been described in the St.

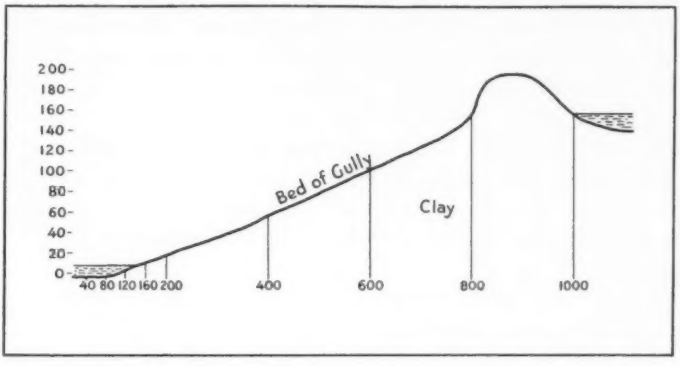

FIG. 1.—Cross-section of a clay divide through which there is no seepage between the upper and lower streams. The final act of capture will be by overflow from the upper stream.

Lawrence Valley.[29] Cases are known where the flow produced a long narrow valley, and it is conceivable that the final act of capture in laminated clay and silt might be brought about violently in this way, although no such cases of capture are known.

Evidence that capture by the underground method is not effective in massive deposits of clayey materials can be found on streams in the St. Lawrence Valley. One of these rivers was meandering on a plain and at the extremity of a meander cut down upon a buried rock hill, downstream from which erosion continued unhindered, with the result that there is a difference of level of 150 feet between the water surface on the two sides of the meander (Fig. 1). The inter-

[29] Ernest A. Hodgson, "The Marine Clays of Eastern Canada and Their Relation to Earthquakes Hazards," *Jour. Royal Astronom. Soc. Canada*, Vol. XXI, No. 7 (1927), pp. 257–64.

vening ridge is composed entirely of clay and is in one place only 150 feet thick at the upper water line. On the downstream side a gully made by a wet-weather stream is cutting back into the ridge and would capture the river above the falls if not interfered with by man. This ridge or natural dam has been very thoroughly investigated by pits and borings, and it is certain that no water is seeping through from the upper stream despite the fact that this clay is intersected by joint cracks which might be expected to transmit some water. It is probable that the cracks are sealed where they approach the river, and it is also probable that the sealing of joint cracks in hard rocks by clay or silt is often effective in preventing the passage of water from the upper stream to the would-be pirate. This example proves that in massive clayey deposits capture must be by surface methods, even when the intervening ridge becomes very narrow. If unhindered by man, the gully in this case would eventually cut back so close to the upper river that in time of flood the river would overflow, cut down rapidly through the clay, and in a few hours completely change the course of the upper stream.

Unconsolidated pervious formations, such as sands and gravels, offer most favorable conditions for capture by the underground method. A pirate stream at low level in permeable sands may lower the ground-water table of a considerable area, depriving one or more high-level streams of their entire ground-water supply and leaving their valleys without streams except in wet weather. The capture of the upper stream is then practically complete, although connection of the valleys may not occur for a very long time. Lane has described a case in the moraines of the lower peninsula of Michigan where the water of the captive stream has been drawn off underground through sand by the pirate, although the valleys are not yet connected.[30] Cases where capture under these conditions is imminent are probably numerous, and the underground method of capture is undoubtedly predominant in permeable sands.

Sudden underground capture may be caused by piping. The sand may be of such size and grading that, with the existing hydraulic gradient, water passing through it disturbs the grains and alters the condition of the sand. With fine sands the flow of water where it

[30] *Op. cit.*, p. 14.

leaves the ground may remove the grains of sand and by a sapping process gradually work back toward the upper stream. In some cases piping may take place with the sudden development of an open channel between the two streams.

The material in which the underground flow of water would be most likely to move the grains is one with grain size between 0.2 and 0.005 mm. in diameter, i.e., fine sand and silt with no clay. The greater the uniformity of the material, the greater is the probability that it will be moved by the flow of water. Grains which will not be moved by water seeping at a low velocity may be moved by a higher velocity. Thus, if the hydraulic gradient is increased, the probability of movement of sand grains is greater. The quantity of water percolating through sand increases in direct proportion to the hydraulic head until the push of the water exceeds the force holding the sand grains in place. Then the structure of the sand suddenly changes to a looser state, the flow of water is greatly increased, sand is moved rapidly, and "piping" occurs.[31]

When layers of uniform, fine sand occur between beds of clayey silt, the conditions are especially suitable for piping. Water moving through the strata of pervious sand may remove the finer material along the contacts with the layers of clayey silt, thus causing an increased flow through the sand strata. Finally, flow through the sand may remove it until an open channel is developed with a roof of denser material.[32] Once this open channel is formed, it will be enlarged by the rapid flow, the roof will collapse, the falling roof material may be removed by the current, and this may continue until an open canyon connects the two streams.

So far as is known no instance of capture by piping has ever been observed, but it is possible that capture has occurred that way in sands. When capture of one stream by another in sand is imminent, it is probable that the underground method is important and that often the captive aids in its own capture. Such a case was studied by the writer on Black Brook, in West Springfield, Massachusetts.

[31] Karl Terzaghi, "Effect of Minor Geologic Details on the Safety of Dams," *Amer. Inst. Min. Met. Eng. Tech. Publ. 215* (1929), pp. 33–41.

[32] Terzaghi, "Earth Slips and Subsidence from Underground Erosion," *Eng. News Record*, July 16, 1931, pp. 91–92.

This brook flows south, and the upper part is entrenched 20–30 feet in the sand plain which floors its broad valley. Near the point in question the brook falls some 30 feet over ledges, below which it is joined by a small, short tributary which heads in springs in a short branch valley extending back upstream into the eastern bluff. The distance from these springs to the main stream above the falls is about 500 feet, and the difference of level is approximately 30 feet. It has been proved that the water of these springs comes out in medium sand and is visibly removing it grain by grain and is gnawing back the head of the valley. This branch valley, which is 300 feet long, has been entirely made by the outflow of seepage. As this continues removing the sand, the head of this branch valley will be pushed back, shortening the distance to the upper stream and increasing the hydraulic gradient, which will, in turn, increase the flow and hasten the process until finally the upper stream is captured and diverted into this branch valley. This gnawing-back of the head of a valley by outflow of seepage water in sand tends to reduce the distance between the two valleys, thus increasing the hydraulic gradient and increasing the possibility of piping with sudden diversion of the upper stream.

SURFACE VERSUS UNDERGROUND METHODS OF PIRACY

The methods of the final act of capture in different formations and under different conditions have already been discussed, and it has been shown that the method will vary according to the nature of the formations. Piracy by the underground method depends upon upon the ability of water from the valley of the upper stream to pass through the ground into the lower stream, and the possibility of this is greatest in the case of soluble formations and of unconsolidated pervious formations. The methods in these two cases are, however, very different, and the results may be different.

Most of the soluble formations such as the limestones and gypsum are in themselves practically impervious; but, once water gets started through cracks, these becomes enlarged by solution, more water passes, and, unless the process is stopped by some other change, the entire upper stream will eventually pass through the underground passages into the pirate. Even in this favorable case,

however, absence of a well-developed joint system may prevent the process from starting, and the underground method cannot be considered as universal even in limestone.

In cases of unconsolidated pervious formations, such as sand, the underground method is almost universal. The pirate stream lowers the ground-water table, depriving the upper stream of its ground-water supply and practically completes the capture of water underground, even though the valleys may not be connected for a long time. Piping may, however, cause a rapid connection of valleys in sands.

Sandstones and other pervious insoluble formations present an intermediate condition. Lowering of the ground-water table and at least partial loss of the ground-water supply of the upper stream is very important in hastening capture but does not insure completion of capture by underground methods.

Many formations—such as the granites and practically all igneous rocks, gneisses, quartzite, slates and most metamorphic rocks except marble, shales, and some conglomerates and sandstones, also clays and silts—are, relatively, both impervious and insoluble. In these rocks, which form the surface of large parts of the earth, water will not enlarge the cracks, and, therefore, where capture is imminent, although some water may pass underground into the lower stream, the effect would generally be negligible, except in the case of badly shattered rocks. It is certain that with impervious, insoluble rocks in the usual condition the upper stream would never lose an appreciable amount of water underground into the lower stream and that the final act of capture must be by surface overflow from the upper stream.

Since impervious, insoluble rocks in fairly massive condition form a large part of the surface of the earth and since in the case of soluble and pervious rocks capture may not always be by the underground method, it is probable that capture by the surface method is more common than by the underground method. In view of these facts it should not be assumed, as has been done by some geologists, that capture will necessarily or even probably be by the underground method. Such an assumption should be made only when it is definitely known that the formations and structure of the region

are such that capture by the underground method is most probable. Even when all the known conditions appear most favorable for capture by the underground method, it may have occurred on the surface, owing to factors not now determinable.

An analysis will now be made of the controlling factors, as far as determinable in one of the cases where it has been assumed that capture took place by the underground method. In his description of stream capture in the Tallulah district, Johnson states:

> Furthermore, there is good reason to believe that the transfer of water may have been nearly or quite complete before an actual surface-valley connection was formed, since as Lane[33] has pointed out, leakage through the rocks from the higher to the lower level will go on for a long time, possibly increasing until all the water from the higher to the lower level passes underground to the lower stream, leaving a dry channel below the point of capture to the first water found in the shrunken, beheaded stream.[34]

Lane described an actual case where water from the upper stream was passing underground to the lower stream, though the two valleys were not yet connected, but he specifically stated that the rock is porous sandstone and did not state or imply that these conditions would occur in all formations. In fact, he said that this condition is the more likely to be true, the more porous the valley bottom of the upper stream is.

The rock in which the capture of the Chattahoochee by the Tugaloo River took place is described by Johnson[35] as mica schist striking northeast-southwest with a variable dip averaging 20° to the southeast. Since the strike is normal to the course of the pirate stream, it was obliged to work back across the structure. This mica schist consists of mica and quartz and is insoluble and practically impervious except for seepage through cracks. Cleavage cracks in mica schist are usually tight, and joint cracks across the structure are not likely to be well developed. The passage of water through such a rock, across the structure, or even along the cleavage cracks would be very slow and would not enlarge the cracks. It is very improbable, therefore, that any important amount of water could pass through this rock from a higher to a lower stream, and, therefore, capture almost certainly took place by surface methods.

The condition in the Tallulah district as described by Johnson is

[33] *Op. cit.*, pp. 12–14. [34] *Op. cit.*, pp. 244–45. [35] *Ibid.*, pp. 223–27.

entirely different from the condition in the case of underground piracy described by Lane in which the rock intervening between the two streams is porous sandstone. In the Tallulah case the underground method of capture is highly improbable, whereas with the conditions described by Lane it was very probable.[36]

A recent example of incipient piracy in which both surface and underground methods are active has been noted by Cressey. In the Catskills a tributary of Kaaterskill Creek is within 25 feet of a tributary of Gooseberry Creek, which is aggrading with pervious gravel. About one-tenth of the total flow of the tributary was seeping through the gravel into Kaaterskill Creek, but a flood channel had formed showing that in high water part of the Gooseberry Creek tributary overflowed into Kaaterskill Creek, the pirate stream. Cressey reports[37] that the underground seepage has little effect upon Kaaterskill Creek and that the final complete capture of the tributary of Gooseberry Creek will undoubtedly be by surface overflow.

This example illustrates the difficulty or impossibility of determining just how the final act of an old capture has taken place. When Kaaterskill Creek has progressed with its capture sufficiently to destroy all evidence of aggradation by the captured stream, it might be assumed by a future geologist that loss of water through the sandstones had played an important part in the capture, whereas headward erosion has been the main factor, and the final act has been governed by aggradation of the upper stream.

Recently the writer has examined several cases of imminent stream capture which illustrate the points under discussion. At Low Gap in Big Stone Ridge, which there forms the boundary between McDowell County, West Virginia, and Tazewell County, Virginia, and is about 2 miles southwesterly from Boissevain, Virginia, the headwaters of Tug Fork have cut back into the ridge and are separated from Laurel Fork of the Bluestone River by a narrow divide which rises about 125 feet above the latter stream. Laurel Fork is

[36] It should be made clear that the question of the underground or surface method of stream capture in the Tallulah district does not affect the main thesis or conclusions of Johnson's paper, and it has been discussed here merely because this unproved assumption had been considered as a proved case.

[37] Oral communication, December, 1934.

flowing northeasterly on a gentle gradient and is at this point about 2470 feet above sea-level. On the side toward Tug Fork the descent from the divide is very steep, and in less than a mile Tug Fork is 500 feet below Laurel Fork. The rock is flat-bedded sandstone and shale of the Lee formation.[38] The conditions here are favorable to seepage of water from Laurel Fork into Tug Fork; and, if capture by the underground method is prevalent in sandstones, the process should be in evidence here. The head of the ravine leading up to this gap is similar in appearance to numerous other ravines which head into the ridge in places where there is no possibility of water seeping from an upper stream. There was no evidence that any seepage coming into this ravine whether from the upper stream or from the general body of ground water was causing slides or in any way hastening the backward cutting of the ravine. On the other hand, there is every indication that the head and sides of this ravine are being actively worn down by weathering and rainwash. This was illustrated during the writer's visit by a terrific downpour. Water poured from every hillside and eroded the soil wherever there was a break in the sod. A fresh gully was being formed in a cowpath which led directly down from the divide toward Tug Fork. It is certain that more erosion of the divide and of the ravine took place in that short storm than in many months of ordinary weather. If there is any seepage from Laurel Fork into the ravine, its effect upon the erosion of the ravine is insignificant compared with floods, and it has practically no effect on lowering the divide.

About a dozen miles southwest of this place the headwaters of Jacob Fork, a tributary of Dry Fork, are cutting back into Big Stone Ridge and threatening to capture the headwaters of Mud Fork, a tributary of the Bluestone River. The elevation of Mud Creek is approximately 3,080 feet and that of the gap in the ridge separating the two creeks, 3,170 feet. On the side of the ridge away from Mud Fork there is a very precipitous descent into Horsepen Cove—1,000 feet in less than a mile. The ridge is formed of the

[38] T. K. Harnsberger, "The Geology and Coal Resources of the Coal-bearing Portion of Tazewell County, Virginia," *Va. Geol. Surv. Bull. 19* (1918), p. 16, geologic map.

Princeton conglomerate which is underlain by the Hinton Formation consisting of red and green sandstone.[39] The only exposed rock is sandstone with a low dip toward Mud Fork. The steep slope into Horsepen Cove shows evidence of soil and rock creep. The only spring near by on this slope is well above the level of Mud Fork and obviously comes from the general body of ground water in the ridge. This spring proves that the ground-water tributary to Mud Fork has not been captured by the lower stream. It is clear that the main work of erosion on this ridge is being done by weathering, soil creep, and rainwash and that there is absolutely no indication that any seepage from Mud Fork is aiding capture in any way even though the rock is sandstone. The divide will be lowered by surface erosion until Mud Fork is able to overtop it in time of flood.

Contrasting with these two examples of imminent piracy in sandstone, there are in near-by Baptist Valley several cases of incipient piracy in limestone. In these latter cases the final act of capture is taking place underground. In several places small streams disappear in sink holes, and just across the low divide are springs which are obviously connected with these sink holes.

Still another example of imminent stream capture which is obviously being completed by surface methods only was seen at Low Gap, about 2 miles north of Princeton in Mercer County, West Virginia. Here Barn Branch of Black Lick Creek has nearly cut through the low divide and is threatening to capture Brush Creek. The divide is only about 30 feet above the normal level of the Creek which rises at least 5 feet during floods. The main line of the Virginian Railroad goes through this divide in a cut and exposes flat-bedded shale with interbedded strata of sandstone. Barn Branch heads on the hill north of the divide and well above the level of Brush Creek. There is no evidence along Barn Branch of permanent springs or of any seepage which might come from Brush Creek. It is obvious that, if uninterfered with by man, the divide would be lowered by weathering and rainwash until Brush Creek is able to overtop it when in flood. Then the stream would cut down rapidly through the soil and weathered rock, and a few floods at most would

[39] *Ibid.*, pp. 12–13.

suffice to change permanently the course of Brush Creek and consummate the piracy.

These examples of incipient piracy reinforce the theoretical conclusions and prove that the method of capture depends upon the nature of the formations and other conditions, and that, except in soluble or very pervious formations, the final act of stream capture is nearly always by surface methods. Since formations which are neither very soluble nor very pervious form a large part of the surface of the earth, it follows that piracy by surface methods is very common.

REPUBLIC GRANITE OR BASEMENT COMPLEX?

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ABSTRACT

Two granites, one of Archean age and one of post-Huronian age, possibly Killarnean, are now generally recognized as present in the Southern Complex. Agreement does not exist regarding the relative amounts of these granites nor the criteria by which their extent should be judged. These factors are discussed, and some hitherto unpublished material is presented. Evidence is cited to show that granite at Republic is younger than a conglomerate there which has been described as containing granite fragments; that the Republic granite is probably continuous with the more northern intrusions, thus making the northern part of the Southern Complex a post-Huronian unit; and, finally, that granite farther south may correlate with this northern unit. The suggestion is offered that such a correlation is favored by a number of different lines of evidence.

INTRODUCTION

Within recent years there has been renewed inquiry into the number of granites and the time of granitic intrusion within the area known as the Southern Complex of Michigan (Fig. 1), a problem about which there has been discussion since 1850. Until recently maps of the area have shown but one granite, of Archean age, but Huronian or post-Huronian intrusions have been described in the literature.[1] Within the past few years more emphasis has been

[1] Summaries of early investigations may be found in the following publications: C. R. Van Hise, W. S. Bayley, and H. L. Smyth, "The Marquette Iron-bearing District of Michigan," *U.S. Geol. Surv. Mono. XXVIII* (1897), pp. 8–148; J. M. Clements, H. L. Smyth, and W. S. Bayley, "The Crystal Falls Iron-bearing District of Michigan," *U.S. Geol. Surv. Mono. XXXVI* (1899), pp. 375–83, 459–61; C. R. Van Hise and C. K. Leith, "Pre-Cambrian Geology of North America," *U.S. Geol. Surv. Bull. 360* (1909), pp. 108–78.

More detailed information may be obtained from the following original references: J. W. Foster and J. D. Whitney, "Synopsis of the Explorations of the Geological Corps in the Lake Superior Land District in the Northern Peninsula of Michigan, under the Direction of J. H. Foster and J. D. Whitney, U.S. Geologists," *31st Congress, 1st Sess., Senate Doc.*, Vol. III, No. 1 (1849–50), pp. 605–25; L. E. Rivot, "Voyage au Lac Supérieur," *Ann. des mines*, Ser. V, Tome VII (1855), pp. 173–328; Tome X (1856), pp. 365–474; Hermann Credner, "Die volsilurischen Gebilde der 'oberen Halbinsel von Michigan' in Nord-Amerika," *Zeits. deutschen geol. Gesellschaft*, Vol. XXI (1869), pp. 516–68; Charles Whittlesey, "Physical Geology of Lake Superior," *Proc. Amer. Assn. Adv. Sci.*, Vol. XXIV (1875), pp. 60–72; M. E. Wadsworth, "Notes on the Geology of

placed on the importance of post-Huronian granitic intrusion,[2] and the most recent map shows the presence of Archean and Killarnean granites.[3]

The problem of the Southern Complex has now reached the stage at which there is rather general agreement that at least two granites are represented in the area, either in outcrops or in conglomerates, and that one of these granites is of post-Huronian age and the other one is of pre-Huronian age. There is not general agreement as to the relative amounts of the two granites—one postulate being that the major part of the granite exposed is of pre-Huronian age, the other that the major part of it is of post-Huronian age. The most

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the Iron and Copper Districts of Lake Superior," *Bull. Mus. Comp. Zoöl.* (1880), Vol. VII, and "A Sketch of the Geology of the Marquette and Keweenawan Districts. Along the Bowstring or South Shore of Lake Superior," *Duluth, South Shore and Atlantic R.R.* (Duluth, 1891), pp. 77–91; C. Rominger, "Marquette Iron Region," *Geol. Surv. Mich.*, Vol. IV, Part 1 (1881), pp. 6–17, and "Geological Report on the Upper Peninsula of Michigan, Exhibiting the Progress of the Work from 1881 to 1884. Iron and Copper Regions," *Geol. Surv. Mich.*, Vol. V (1895), pp. 1–94; C. R. Van Hise, "An Attempt To Harmonize Some Apparently Conflicting Views of Lake Superior Stratigraphy," *Amer. Jour. Sci.* 3d ser., Vol. XLI (1891), pp. 117–37; H. L. Smyth, "A Contact between the Lower Huronian and the Underlying Granite in the Republic Trough, near Republic, Michigan," *Jour. Geol.*, Vol. I (1893), pp. 16–29; C. R. Van Hise, W. S. Bayley, and H. L. Smyth, "The Marquette Iron-bearing District of Michigan," *U.S. Geol. Surv. Mono. XXVIII* (1897), pp. 190–95, 212–13, 411, 526, 542; J. M. Clements, H. L. Smyth, and W. S. Bayley, "The Crystal Falls Iron-bearing District of Michigan," *U.S. Geol. Surv. Mono. XXXVI* (1899), pp. 39, 51, 77, 160, 190–95, 383–84, 389–90, 401–2, 429, 461–62, 469; C. R. Van Hise and C. K. Leith, "The Geology of the Lake Superior Region," *U.S. Geol. Surv. Mono. LII* (1911), pp. 299, 304, 327.

[2] L. P. Barrett, F. G. Pardee, and W. Osgood, Geological Map of Iron County, 1929; C. O. Swanson, *Report on the Portion of the Marquette Range Covered by the Michigan Geological Survey* (1929), pp. 2, 13–15; Justin Zinn, *Report on the Portion of the Marquette Range Between Humboldt and Lake Michigamme Covered by the Michigan Geological Survey* (1930), pp. 3, 16–17; C. A. Lamey, "Granite Intrusions in the Huronian Formations of Northern Michigan," *Jour. Geol.*, Vol. XXXIX (1931), pp. 288–95, "The Intrusive Relations of the Republic Granite," *ibid.*, Vol. XLI (1933), pp. 487–500, "Some Metamorphic Effects of the Republic Granite," *ibid.*, Vol. XLII (1934), pp. 248–63, and "The Palmer Gneiss," *Geol. Soc. Amer. Bull. 46* (1935), pp. 1137–61; C. K. Leith, R. J. Lund, and A. Leith, "Pre-Cambrian Rocks of the Lake Superior Region," *U.S. Geol. Surv. Prof. Paper 184* (1935), p. 20; C. B. Slawson, "High Iron Tourmaline from the Marquette Iron Range," *Min. Soc. Amer. Abstracts, Sixteenth Ann. Meeting* (1935), p. 4; R. M. Dickey, "The Granitic Sequence in the Southern Complex of Upper Michigan," *Jour. Geol.*, Vol. XLIV (1936), pp. 317–40.

[3] Leith, Lund, and Leith, *op. cit.*, Pl. I.

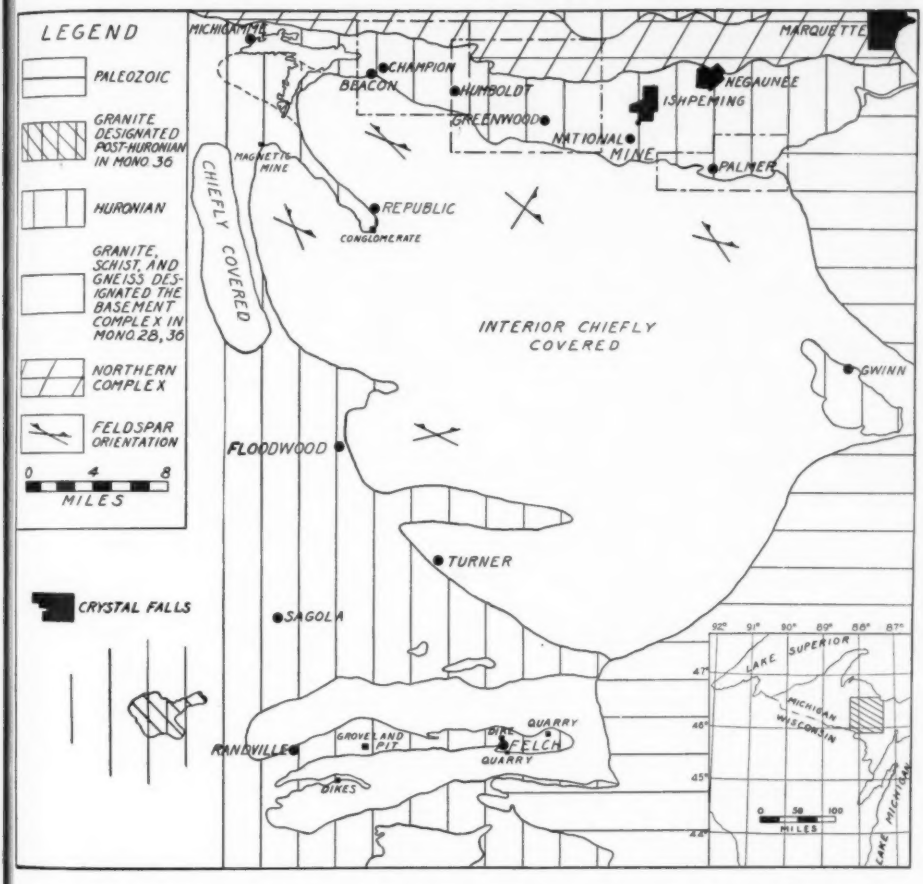

FIG. 1.—Map showing granitic area originally designated "Southern Complex" and surrounding region. The symbol used for feldspar orientation indicates strike and dip of feldspar phenocrysts, the two strike lines representing the boundaries of the greatest concentration of observed strike directions. Note that the regional pattern is northwesterly strike with northeasterly dip.

recent supporter of the former concept is Dickey,[4] who believes that the principal granite of the area is an Archean granite-porphyry; whereas the latter concept is defended by Lamey,[5] who believes that much of the granite-porphyry is of post-Huronian age. Dickey's conclusions apparently were based chiefly on (1) field lithology and texture of granite, (2) secondary structure of granite, (3) lack of observed intrusion of granite-porphyry into Huronian formations, and (4) conglomerates thought to contain boulders of previously sheared granite-porphyry and to be of Huronian or pre-Huronian age. His conclusion apparently was influenced, also, by his belief that the distribution of younger granite is typically spotty and irregular and that it forms no masses of great size or remarkable continuity. On the other hand, Lamey's conclusions were based on the following criteria: (1) granitic dikes marginal to the Southern Complex cutting formations as young as Upper Huronian; (2) discordant as well as accordant intrusive contacts between granite of the Southern Complex and Huronian formations; (3) continuity of granite in the northern part of the complex; (4) character, degree, and extent of metamorphism of Huronian formations, and position of such metamorphosed formations with reference to granite of the Southern Complex; (5) similarity of accessory minerals obtained from widely separated specimens of granite of the Southern Complex and the apparent relationship between the distribution of those minerals and certain metamorphic minerals occurring in the Huronian formations; (6) primary structure of granite of the Southern Complex and its relationship to regional structure; (7) general absence of conglomerates adjacent to the Southern Complex having *known* relations to both granite and the Huronian and containing unquestionable fragments of the granite under consideration, and extremely sporadic occurrence of any conglomerates stated to contain such fragments.

It is the writer's belief, based on field observations during the last 7 years and laboratory study of about one thousand hand specimens and three hundred and fifty thin-sections, that there is now enough evidence to show (1) that post-Huronian granite forms essentially a continuous northern border of the Southern Complex throughout a

[4] *Op. cit.* [5] *Op. cit.*

distance of at least 23 miles and probably as much as 30 miles; (2) that this granite grades southward into the Southern Complex and apparently is an integral part of that mass; (3) that the granite at Republic is younger than a conglomerate there which has been cited as evidence of the Archean age of the granite; (4) that marginal shearing and deformation of the granite after solidification of the margins does not indicate a pre-Huronian age of the granite; and (5) that different lines of investigation all point to the same conclusion, namely, that a large part of the granite formerly considered to be Archean is in reality post-Huronian. A discussion of these points is attempted in this paper, the northern part of the complex being considered first.

THE NORTHERN PART OF THE SOUTHERN COMPLEX

Continuity and extent of peripheral post-Huronian granite.—It has been stated that the distribution of post-Huronian granite is typically spotty and irregular, and that it forms no masses of great size or remarkable continuity,[6] but published papers indicate a different condition. Swanson,[7] working near Greenwood (Fig. 1), mapped the southern granitic "basement" as chiefly post-Huronian for an east-west distance of 8 miles; and Zinn,[8] working in an adjacent area, extended post-Huronian granite westward 5 miles, to Beacon (Fig. 1), thus establishing a continuous belt of post-Huronian granite 13 miles in length. Lamey recognized this continuous belt and cited evidence indicating that a tongue of post-Huronian granite extends westward beyond the southern end of Lake Michigamme (dashed line, Fig. 1).[9] Granite exposures in this western tongue cannot be followed as continuously as in the belt from Beacon eastward, but numerous dikes and marked contact metamorphism[10] are deemed sufficient evidence to establish the presence of a 7-mile belt of post-Huronian granite extending westward from the Beacon area. If such is the case, this indicates practically continuous post-Huronian granite over a distance of about 20 miles. To the east-

[6] Dickey, *op. cit.*, p. 334. [7] *Op. cit.* [8] *Op. cit.*

[9] "The Intrusive Relations of the Republic Granite," *loc. cit.*, pp. 496–98, 499–500.

[10] Lamey, "Some Metamorphic Effects of the Republic Granite," *loc. cit.*, pp. 250–53; Van Hise and Leith, "The Geology of the Lake Superior Region," *loc. cit.*, p. 268.

ward of the areas mapped by Swanson and Zinn, in the vicinity of Palmer, Lamey has shown the presence of post-Huronian granite throughout a distance of 7 miles.[11] Between the Palmer and Greenwood areas there is a small area south of Ishpeming, in which the National Mine is located (Fig. 1), which has not been described by recent investigators. Since this area forms a connecting link, 3 miles long, between areas containing continuous exposures of post-Huronian granite, a brief description of it is pertinent.

In the National Mine area the Huronian formations are flanked southward by scattered outcrops of diorite, granite, gneiss, schist, and some recognizable sediments. At the mill of the Hercules Powder Company there is a bold cliff of white quartzite, presumably of Huronian age as no older quartzite is known in this region. Associated with this quartzite are granite and a dioritic rock. Both the quartzite and the diorite are cut by granite which occurs as dikes varying in width from a few inches to about 65 feet and as intrusive masses which project up into the surrounding rocks but do not appear at the surface. In other places in the area, gneiss and schist are intermingled with the granite, the granite cutting across the schistosity in some instances, and the gneiss grading into granite. The scattered nature of outcrops does not permit definite correlation, but the occurrence of quartzite cut by granite, the proximity of this area to the adjoining Palmer and Greenwood areas, and the fact that known post-Huronian granite may be traced westward and eastward into this area suggest that it is actually continuous with these other areas. If such is the case, it unites the Palmer and Greenwood units, forming a continuous belt of post-Huronian granite 23 miles long. If to that there be added the 7-mile belt extending across Lake Michigamme, the total length is 30 miles. This indicates, at least to the writer, that the distribution of post-Huronian granite is far from spotty and irregular but that it is essentially continuous with the northern margin of the Southern Complex.

Relation of peripheral post-Huronian granite to the Southern Complex.—Three concepts regarding the origin of post-Huronian granite have been advanced: (1) it originated by "partial liquefaction of a zone beginning near the original base of the Huronian";[12] (2) a

[11] "The Palmer Gneiss," *loc. cit.*

[12] Swanson, *op. cit.*, p. 15.

post-Huronian batholith intruded Archean granite but is exposed chiefly locally around the margins of the older granite;[13] (3) the major granitic intrusion was in post-Huronian time, and hence much of the adjacent granite of the Southern Complex is actually of post-Huronian age.[14] Zinn apparently accepts Swanson's explanation of partial liquefaction, although he states that any Lower Huronian sediments that may have been present along the south side of the Marquette syncline in the area in which he worked were probably engulfed in the post-Huronian granite,[15] a concept which certainly indicates, at least to the writer, the invasion of a large body of magma. Dickey apparently favors either Swanson's explanation or the intrusion of a Killarnean batholith which is chiefly unexposed, but he also mentions the possibility of previously existing granite-porphyry being "engulfed by the Killarney granite,"[16] which again indicates a large body of magma.

The writer does not accept either of the first two concepts regarding the origin of post-Huronian granite because to him they do not appear to be in accord with observed conditions of metamorphism, and there apparently are no characteristics by which marginal post-Huronian granite can be separated from the granite to the south of it, with which it appears to be continuous. In the Palmer area there can be no doubt from Bayley's excellent descriptions that granite intrusions into Huronian rocks formerly described as Palmer gneiss were regarded as a part of the great granite mass to the south.[17] Surely the discovery that the intruded rocks are of Huronian instead of Keewatin age can be no reason for separating the intrusions from the similar larger granite mass to the south. The two characteristics upon which Dickey apparently relies for separation of Archean from Killarnean granite are porphyritic texture and deformation of the former granite, yet he states: "In that portion of the Southern Complex which lies immediately south of the Marquette synclinorium, the deformation of the granite-porphyry is not generally apparent," and he offers several explanations to account for the absence of the

[13] Leith, Lund, and Leith, *op. cit.*, Pl. I.

[14] Lamey, "The Intrusive Relations of the Republic Granite," *loc. cit.*, p. 498.

[15] *Op. cit.*, pp. 4–5.

[16] *Op. cit.*, p. 332.

[17] "The Marquette Iron-bearing District of Michigan," *loc. cit.*, pp. 211–13.

criteria whereby the age of the granite is fixed as Archean.[18] To assume that the texture of dikes and small intrusive masses should be the same as that of the parent mass obviously is erroneous. Further, no criteria for separation of post-Huronian granite from granite to the south of it were established by Swanson or by Zinn. Indeed, the writer knows of no place in this northern part of the Complex where one can with assurance show acceptable criteria whereby post-Huronian granite can be separated from the granite to the south of it. Moreover, the writer's observations indicate a gradual change from Huronian sediments through gneissic and granitic material into granite as one goes southward, and these observations are substantiated by those of Swanson and Zinn.

In addition to the lack of criteria for separating post-Huronian granite from granite to the south of it, metamorphism of the Huronian rocks indicates extensive intrusion of a large mass of magma. This metamorphism has been described briefly by the writer[19] and also by Swanson[20] and by Zinn.[21] In each instance it was attributed to contact action. Moreover, certain accessory minerals of the granite are the same as some additive metamorphic minerals occurring in the adjacent metamorphosed Huronian rocks.[22] It appears to the writer that such extensive contact metamorphism which persistently follows the periphery of the Southern Complex could have been produced only by batholithic intrusion. As the peripheral post-Huronian granite grades southward into the Southern Complex and apparently is an integral part of that mass, it appears that much of the Southern Complex must of necessity be composed of post-Huronian granite and represent a younger rather than an older batholithic intrusion.

Republic and vicinity.—If much of the granite of the Southern Complex is of post-Huronian age, it appears logical that it should no longer be termed Southern Complex, which implies the pre-Huronian basement upon which Huronian formations were de-

[18] *Op. cit.*, pp. 331–33.

[19] "Some Metamorphic Effects of the Republic Granite," *loc. cit.*

[20] *Op. cit.* [21] *Op. cit.*

[22] Lamey, *Ann. Rept. Nat. Research Council, Appendix F* (1933), pp. 3–4; also "Some Metamorphic Effects of the Republic Granite," *loc. cit.*, p. 262.

posited, but should be named from some type locality. Therefore Lamey proposed the name "Republic granite"[23] because of excellent exposures and typical development in the vicinity of Republic. Recently it has been stated that this granite is of Archean age and that this name is a misnomer,[24] these conclusions apparently being based upon the belief (1) that deformation of granite near its contact with Huronian formations indicates pre-Killarnean solidification of magma and hence pre-Huronian solidification; (2) that lithologically the granite is similar to other granite which Dickey believes to be of pre-Huronian age; and (3) that a conglomerate at Republic, beneath the Middle Huronian Ajibik quartzite, contains material thought to represent boulders and other detritus derived from the granite in question.[25]

The conglomerate at Republic,[26] which occurs at the southern end of the trough (Fig. 1), near the ball park, was first described by Smyth,[27] who thought it contained granite fragments and boulders and who cited it as the base of the Lower Huronian series and the only basal conglomerate then known on the south side of the Marquette synclinorium. Regardless of several previous examinations of this conglomerate by the writer, it was re-examined twice during the summer of 1936. On no occasion was it found to contain granite pebbles or boulders, nor could there be discovered an arkosic and chloritic matrix such as has been described.[28] Specimens were obtained of as many different phases of this conglomerate as were observed, and from these and specimens already on hand fourteen thin-sections were cut, making a total of twenty thin-sections available for study of this conglomerate. From this laboratory and field study, the following description and interpretation was formulated.

[23] "The Intrusive Relations of the Republic Granite," *loc. cit.*, pp. 498–99.

[24] Dickey, *op. cit.*, pp. 327–28, 340. [25] *Ibid.*, pp. 324–28.

[26] The presence of this conglomerate and other features in this vicinity, mentioned by Dickey, were known to the writer prior to his publications regarding this area. These features had been examined in the field several times, and although omitted from discussion in published material they were treated in some detail in unpublished manuscript. Attention was called to this manuscript and its availability on interlibrary loan (see "Some Metamorphic Effects of the Republic Granite," *loc. cit.*, p. 250).

[27] *Op. cit.;* see also Van Hise, Bayley, and Smyth, *op. cit.*, pp. 532–33.

[28] Dickey, *op. cit.*, p. 327.

Field relations are best described with the aid of an outcrop sketch (Fig. 2). To the north, Middle Huronian Negaunee iron-formation (2)[29] and Ajibik quartzite (1 and 3) are exposed, and to the south

FIG. 2.—Sketch of outcrop boundaries at the southern end of the Republic trough. Numbers refer to descriptions in the text, and letters to locations of detail sketches (Fig. 3).

[29] Numbers in parentheses refer to locations on the outcrop sketch.

outcrops consist chiefly of granite. Associated with the granite are conglomeratic, quartzitic, schistose, and gneissic material, the conglomerate confined chiefly to the western side. Some details of these relations are shown in Figure 3. The strike of the Negaunee iron-formation (*2*), about N. 20° E. (dip 65° westerly), apparently is directly into the granite and associated material. However, the strike is known to change rapidly in this vicinity, at the southern end of the Republic trough, so to the southward it may more nearly parallel the southern edge of the Ajibik quartzite outcrop (*3*). Quartzitic material associated with the granite to the south gives indications of strikes about N. 30° E. with westerly dip (*4*), N. 55° W. with southerly dip (*7*), and N. 25° W. with northerly dip (*9*).

It is the writer's opinion that the conglomerate on the western side of the granite outcrop contains no pebbles or boulders of granite and that the matrix of this conglomerate is chiefly a quartzitic one. In the field the boulders and pebbles appear to be of quartzitic, schistose, and gneissic character, many of them apparently composed chiefly of quartz and biotite. Microscopic examination of such material discloses an almost total absence of feldspar, but the presence of much mosaic quartz, some cherty to rounded quartz, and "nests" of biotite in interlocking and cross-cutting crystals, with which in some instances muscovite is prominently interwoven, the muscovite apparently later than the biotite. The matrix of this conglomerate, as seen in the field and in hand specimen, may be described as a quartzitic and schistose one which is prominently banded in some instances, the banding apparently being produced by biotitic layers alternating with quartzitic and sericitic ones. Microscopic examination verifies the megascopic indications and discloses that the average matrix consists of about 80 per cent mosaic quartz, 15 per cent biotite, and 5 per cent feldspar and chlorite combined. The matrix, therefore, is far from arkosic. In exceptional cases it may contain as much as 20 per cent feldspar, but in such instances it is near the contact with quartzose *intrusions* containing a small amount of feldspar.

In two places within the conglomerate outcrop, low on the side of the hill and partly concealed by vegetation, there were found quartzose dikelike intrusions cutting the conglomerate (*8* and *10*),

both of these intrusions containing minor amounts of feldspar. In one instance (*8* and *A*), the dikelike body appears to be discontinuous, one part apparently containing quartz only, the other part containing both quartz and feldspar, this latter part having both concordant and discordant relations to the schistosity of the surrounding material (Fig. 3*A*). Near the edges of this intrusion there were found small quartz injections parallel with the surrounding schistosity, these injections containing pyrite and chalcopyrite. In another instance (*10* and *B*), the dikelike intrusion is composed chiefly of quartz with some feldspar concentrated at the edges, and cuts through gneissic to schistose material which is flanked on one side by conglomerate (Fig. 3*B*). Between these two intrusions, lying on the ground at the base of the slope among some bushes (*C*), is a small talus block of material apparently from the slope above, which shows another intrusion (Fig. 3*C*). This intrusion consists of two lenticular pegmatitic masses containing appreciable amounts of feldspar, connected by quartz, and the surrounding material apparently represents the matrix of the conglomerate. It is possible that lenticular intrusions of this nature may have been mistaken for boulders.

Material similar to the conglomerate matrix, of quartzitic, schistose, and gneissic nature, exists also along the northwestern and northern foot of the granite outcrop in question (*4*, *5*, *6*, and *D*; also Fig. 3*D*). Microscopic examination of some of this material (*5* and *6*) shows the presence of small feldspar or quartz-feldspar dikelets, some of them cutting across the schistosity. Also, the more metamorphosed phases contain very small garnets, appreciable amounts of muscovite, and show rather clear evidence of replacement of quartz by feldspar. In one instance (*5*), myrmekitic texture was observed adjacent to one of these dikelets.

It seems apparent from the foregoing descriptions that the conglomerate associated with the granite at Republic not only does not contain granite pebbles and boulders, and has not an arkosic matrix, but is actually cut by dikelike intrusions which have emanated from some larger granite mass, apparently the granite associated with the conglomerate. A survey of the adjacent Huronian formations yields additional information regarding age relations.

Huronian formations immediately to the north of the granite and

conglomerate show marked evidence of contact metamorphism, and throughout the vicinity of Republic similar conditions prevail near the southern granite. These conditions have been described pre-

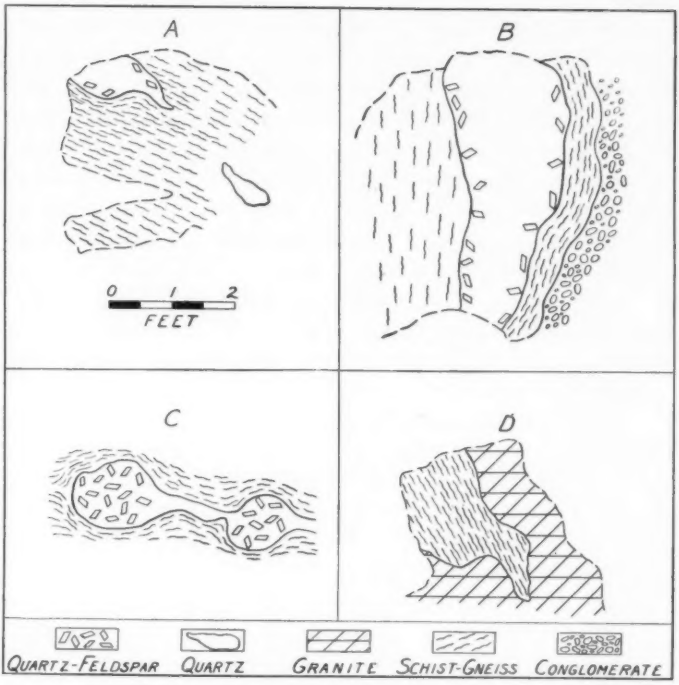

FIG. 3.—Detail sketches of parts of the conglomerate and granite outcrop south of the Republic trough. The same scale is used throughout. *A* and *B*, Quartz-feldspar intrusions into schistose matrix and conglomerate. *C*, Sketch of surface of talus block showing pegmatitic intrusion into conglomerate matrix. *D*, Sketch showing relation of matrix to granite.

viously.[30] If the granite in this vicinity is older than the Huronian formations, as postulated by Dickey, one is faced with the anomalous condition of extensive contact metamorphism without any intrusion that produced it.

[30] Lamey, "Some Metamorphic Effects of the Republic Granite," *loc. cit.*, pp. 253–56; "The Intrusive Relations of the Republic Granite," *loc. cit.*, pp. 492–93.

The writer previously cited, as another indication of post-Huronian granitic intrusion in the Republic area, conditions at the West Republic mine.[31] On the east bank of the Michigamme River is the dump pile of an abandoned iron mine, and across the river in the projected line of strike there is a large granite hill, the iron-formation and underlying Ajibik quartzite being missing. Material on the dump consists chiefly of specularite and magnetite, but some of this material contains pyroxene crystals and is cut by dikelike veins, chiefly of quartz but some composed of feldspar. Feldspar dikelets in material collected from this dump vary in width from a fraction of an inch to about 3 inches. These facts led the writer to suggest that the field relations indicate granite invasion across the strike of the Negaunee iron-formation. Objection was recently made to this statement on the ground that the granite in question is identical with the granite-porphyry associated with the conglomerate at the south end of the Republic trough,[32] and Dickey concluded that

> evidently . . . . the absence of the Ajibik quartzite and Negaunee iron-formation along the southwest margin of the Republic trough is due to erosion, since the Huronian of this part of the area lies unconformably upon the Laurentian granite-porphyry.

The writer is not averse to the concept of erosional thinning or perhaps complete removal, locally, of the Ajibik quartzite and the Negaunee iron-formation, but such thinning or removal fails to constitute, to him, proof that granite does not cut discordantly across the strike of the Huronian formations at this locality, but does indicate a means of facilitating such intrusion. Smyth, although believing the Republic conglomerate previously discussed to contain granitic debris, nevertheless recognized that a real difficulty was presented by the disappearance of the Middle Huronian rocks at the West Republic mine. After calling attention to the fact that underground the iron-formation was followed nearly to the west bank of the river, and that apparently "the lower series continue without sensible change in strike as far as the river, and there terminate squarely against the granite," he concluded that

[31] "The Intrusive Relations of the Republic Granite," *loc. cit.*, pp. 492–93.

[32] Dickey, *op. cit.*, pp. 327–28.

such relations can be best explained by supposing that the granite on the west bank either had intruded the lower series or had been brought to the level of the old surface by a fault before Upper Marquette time.[33]

No such fault has been shown to exist. However, the granite associated with the conglomerate at Republic has been shown to be post-Huronian. Consequently the concept previously advanced by the writer, that the granite cuts discordantly across the strike of the Huronian formations, appears to be correct. A similar concept was advanced by Swanson to account for the absence of Upper Huronian iron-formation in the Greenwood area.[34]

Unity of the northern area.—Evidence for the existence of post-Huronian granite of considerable extent in the vicinity of Republic is similar to that farther north. Indeed, metamorphic rock types in the Republic area may be duplicated in the more northern area where the cause of metamorphism has been agreed by several workers to be intrusion of post-Huronian granite. To the writer these and other facts indicate the general unity of post-Huronian granitic invasion on a large scale throughout the entire northern part of the area designated Southern Complex and incline him to a belief that the term "Republic granite" is not a misnomer. This unity is indicated not only by granite intrusions but also by textural gradation of granite; by gradation of metamorphosed Huronian formations into gneiss, gneissoid granite, and porphyritic granite; by character and degree of metamorphism; by accessory minerals of the granite; and by primary granite structures and their relation to regional structure.

There are two outlying areas near the northern part of the Republic granite which have not been carefully investigated and which are, therefore, excluded from this generalization regarding the unity of the northern area. One of these is the oval area about 6 miles west of Republic, apparently detached from the main mass and, to the best of the writer's knowledge, chiefly covered. The other is a small area southeast of Marquette, separated from the Palmer area by a distance of about 6 miles in which granitic exposures are largely lacking. The writer's observations in this Marquette area lead him to believe that the granite there is intrusive into Lower Huro-

[33] Van Hise, Bayley, and Smyth, *op. cit.*, p. 542. [34] *Op. cit.*, p. 13.

nian Mesnard quartzite. However, this granite can be traced westward but a short distance. Between it and the Palmer area, in the vicinity of Lake Mary, there is a conglomerate which was early described by Van Hise[35] and cited as evidence that the granite to the south is Archean. So far as the writer is aware, there is no conclusive proof of the age of this conglomerate. Some exposures show conglomerate dipping southward about 80° containing numerous pebbles and boulders of quartz, chert, and probably quartzite, in a matrix consisting chiefly of quartz and reddish feldspar, slightly cross-bedded in some instances, and larger masses of nearly pure feldspar with some quartz varying in shape from lenticular to irregular, some of them parallel to the arkosic bedding, others cutting across it. The impression was gained that these larger masses represent litpar-lit and dikelike intrusions of younger granite into this arkosic material, but the investigation permitted by the time available does not permit definite conclusions to be stated. Moreover, these observations are not entirely in accord with those of some other investigators who examined this or another conglomerate in this vicinity, as they noted jasper and granite fragments, in addition to the ones cited, and a lesser degree of dip. So far as is known, none of these observations gives conclusive evidence as to the age of the conglomerate nor its relation to the granite of the Southern Complex or to post-Huronian granite near Marquette.

THE SOUTHERN PART OF THE COMPLEX

In the southern part of the Complex it has been definitely established that post-Huronian granite intrusions exist in a narrow belt about 15 miles long, extending approximately from Randville to a few miles east of Felch (Fig. 1),[36] and there is no lack of evidence indicating extensive contact metamorphism of Huronian formations.[37] The question again arises, however, as to the extent of post-Huronian intrusion and its relation to the granite which flanks the Huronian formations.

[35] "The Marquette Iron-bearing District of Michigan," *loc. cit.*, p. 240.

[36] Lamey, "Granite Intrusions in the Huronian Formations of Northern Michigan," *loc. cit.*, pp. 289–92.

[37] Lamey, "Some Metamorphic Effects of the Republic Granite," *loc. cit.*, pp. 256–58; "The Intrusive Relations of the Republic Granite," *loc. cit.*, pp. 490–91.

As an indication of the extent of post-Huronian granitic invasion and granite relationship the writer previously cited conditions at quarries southeast of Felch (Fig. 1).[38] Metamorphosed Randville dolomite in one quarry and schist in another quarry are both intruded by granite. Structural relations indicate that the dolomite to the west plunges eastward and underlies the schist. The shortest distance between schist and dolomite outcrops is about 150 feet, but granite associated with the schist is exposed within about 137 feet of the dolomite. Because of structural conditions, high degree and character of metamorphism, and the fact that granite intrudes both dolomite and schist, it was suggested that here is an indication that the main body of granite of the Southern Complex in this vicinity is the same as the known post-Huronian granite and is actually of later age than the Huronian rocks. It is worthy of note that the granite to the southwest of this quarry is designated Killarnean on the revised Lake Superior map.[39]

Objection to this concept has been offered by Dickey, who postulates that the schist exposed at the eastern quarry is of Keewatin age, that the granite intruding this schist is of Laurentian age, and that the granite intruding the Randville dolomite is of Killarnean age, and *assumes* that a fault of some magnitude separates the outcrops in the two quarries.[40] Dickey's concept apparently is based on the belief that "mashing of the granite-porphyry east of the schist quarry establishes it as Laurentian"; that the schist, since it is intruded by this granite and the schistosity deformed by intrusion, must be older than the granite and hence Keewatin; and that "the structural trends in the two quarries are obviously entirely discordant."[41] This latter conclusion apparently is based on (1) measurements of strike and dip of *cleavage* and *foliation* of rocks around the eastern quarry as compared almost wholly with strike and dip of *bedding* of rocks around the western quarry, the latter rocks being part of a pitching structure, and (2) faults apparently of very small magnitude and indicating but slight displacement, cited as present in the schist of the eastern quarry and absent in the

[38] "The Intrusive Relations of the Republic Granite," *loc. cit.*, pp. 490–91.

[39] Leith, Lund, and Leith, *op. cit.*, Pl. I.

[40] *Op. cit.*, pp. 335–38. [41] *Ibid.*

dolomite of the western quarry. These features, and the belief that "the Huronian rocks have been subjected to only one major orogenic disturbance,"[42] apparently were the basis for the assumption that a major fault, probably of general north-south trend, separates the rocks of the two quarries.

The writer was well aware of the relations between strike of the bedding at the western quarry and strike of schistosity at the eastern quarry, as shown by previous statements and a sketch showing average direction of schistosity and its relation to surrounding granite,[43] and was also aware of other structural features in this area. However, they were differently interpreted. The discordance of strike between rocks of these two quarries, if it be permissible to make a comparison of the features measured, and the difference in rock character and composition, are no greater than may be found in different parts of many single Huronian outcrops within as little or less distance. Therefore, if such a single outcrop were partially obscured so that two exposures were seen, with a covered area between, should it be assumed that they were separated by faulting? In this particular case, it may be cited that to the south of the quarries in question almost continuous granite outcrop was followed essentially foot by foot without finding any evidence of a north-south fault which could be projected northward between these two quarries. Moreover, neither the small faults in the schist nor the mashing around the margins of the granite appears to vitiate the possibility of the main mass of granite here being post-Huronian. In the case of intrusion of batholithic proportions, accompanied by orogeny, would not cooling be a slow process, with solidification first around the margins of the intrusive, and would subsequent shearing and mashing of such marginal parts be an unreasonable possibility during later stages of intrusion and orogeny? Also, in similar manner could not small marginal faults arise locally in the intruded rocks? Again, is there positive evidence that the Huronian rocks have been subjected to only one major orogenic disturbance? It has been stated that the known periods of faulting in the Lake Superior region are pre-

[42] *Ibid.*

[43] "The Intrusive Relations of the Republic Granite," *loc. cit.*, pp. 490–91.

Cambrian, post-Cambrian, post-Cretaceous, and post-Pleistocene,[44] and although the authors of that statement believed the post-Pleistocene to be eliminated as a period of major faulting, and favored pre-Cambrian time for the development of original faulting along large escarpments, they nevertheless recognized the possibility of later major faulting. Moreover, rocks as recent as Silurian have been involved in folding and faulting at Limestone Mountain, and Ordovician rocks of Canada have suffered folding.

It is recognized that the relatively abrupt change in character of material in these two quarries is somewhat puzzling. However, to the writer a much better explanation would be found in postulating that the amphibole schist may represent metamorphosed Hemlock volcanics, which have never been described as present in this immediate area but which occur in the adjoining Crystal Falls district in thicknesses stated to vary from 1,000 to 10,000 feet. A discussion of this possibility appears in an unpublished manuscript of the writer's[45] but has not heretofore been suggested in print because but little work has been done on this particular problem. It is suggested here only because of the bearing it may possibly have on the relationship of rock types in these two quarries. If the schist overlies the Randville dolomite, as the structural relations indicate, it has the proper stratigraphic position for the Hemlock formation.

After a reconsideration of all evidence, and a re-examination of the field relations at the two quarries in question, the writer still believes that his previously stated conclusion that the granites of these two quarries are both of post-Huronian age is not illogical, especially in view of the fact that dikes cut both the Randville dolomite and the Vulcan iron-formation a short distance northward (Fig. 1), and the granite immediately to the southwest is designated Killarnean.

In other parts of this southern area there are similar indications that the post-Huronian dikes are genetically connected with the main mass of granite which has been designated Archean. An in-

[44] Van Hise and Leith, "The Geology of the Lake Superior Region," *loc. cit.*, p. 117.

[45] "The Intrusive Relations and Metamorphic Effects of the Republic Granite" (unpublished manuscript [1933], on file at Deering Library, Northwestern University), pp. 171–75.

stance of this character is to be found in the area between the Groveland mine, where a granite dike cuts Vulcan iron-formation, and an outcrop of Sturgeon quartzite to the southwest, cut by a number of granite dikes (Fig. 1), some of which contain xenoliths of quartzite.[46] Between these two places are scattered outcrops of granite and gneissic material which resembles very closely material known to have been derived from quartzite as a result of granite metamorphism. Again in this instance it is interesting to note that granite to the south of this Sturgeon quartzite is designated Killarnean on the revised Lake Superior map.[47] Significant, also, is a concept previously advanced by Smyth in connection with granite dikes cutting Huronian formations in this southern area. He stated that "the known granites within the Archean" might actually be "low-lying and larger masses with which such dikes are genetically connected."[48] It may be pertinent, as well, to call attention to an area about 9 miles west of the Groveland mine (Fig. 1), in the Crystal Falls district, in which relatively large masses of granite cut Upper Huronian Michigamme formation and have produced metamorphism similar to that occurring near Lake Michigamme farther north. This area was described by Clements.[49]

A small conglomerate outcrop has recently been cited as evidence that the major part of the granite of this southern area is of pre-Huronian age.[50] Again, as in other instances, the writer was aware of this and other conglomerates previously cited in the literature.[51] However, it is believed that relations of Huronian rocks to the main mass of granite in this area are not established by these isolated outcrops and that, indeed, the actual age of the conglomerates is not known. Some of these conglomerates do contain granitic debris, as is very well shown at the falls of the Sturgeon River. There a red, arkosic matrix, exhibiting cross-bedding in places, encloses pebbles

[46] Lamey, "Granite Intrusions in the Huronian Formations of Northern Michigan," *loc. cit.*, p. 290.

[47] Leith, Lund, and Leith, *op. cit.*

[48] "The Crystal Falls Iron-bearing District of Michigan," *loc. cit.*, pp. 389–90.

[49] *Ibid.*, pp. 164, 190–95, Pls. III and XVIII.

[50] Dickey, *op. cit.*, pp. 328–29.

[51] "The Intrusive Relations and Metamorphic Effects of the Republic Granite" (unpublished manuscript on file at Deering Library), pp. 58–59.

and boulders of quartz, white quartzite, pink chert, gray banded chert, apparently a lean iron-formation (quartzitic material containing magnetite metacrysts), quartz-porphyry, red fine-grained granite, red coarser granite, and red feldspar. The fragments vary in size, the largest observed being about 6 or 8 inches long and from 2 to 4 inches wide, are elongated in a general east-west direction, and dip south about 80°. The age of this conglomerate is unknown, hence it proves merely that some granite was exposed at the time of its formation, but it does not prove the age of that granite or whether its occurrence was widespread or local. Time for very careful detailed mapping of this conglomerate, collection and study of all material contained in it, and classification of that material as to abundance, was not available. Because of the variety of fragments observed, it is believed that such a study might possibly add to our meager knowledge of the significance of some of these conglomerates.

GRANITE CORRELATION

The fact that post-Huronian granite occurs in some abundance both in the northern and toward the southern part of the Southern Complex has been definitely established during the last 7 years, and the unity of the northern part of this granite has been indicated. There remains the possibility of correlating the younger southern granite with the northern post-Huronian granite. With this in mind, it may be well to consider the original basis for granite correlation within the Southern Complex.

Correlation between northern and southern granitic areas apparently depended on first establishing indications that the granite was a part of the Basement Complex, by means of conglomerates or gradational phases, and then making connection with other areas on the basis of similarity of conditions. Relations in the Sturgeon River Tongue appear to have furnished the correlation between the northern and the southern parts, although it was stated that "no contacts of this granite-schist complex with the bedded rocks of the Sturgeon River Tongue have been discovered."[52] However, on the basis of conglomerates near the Sturgeon River and at Republic,[53]

[52] Clements, Smyth, Bayley, and Van Hise, *loc. cit.*, pp. 461–62.

[53] *Ibid.*

it was believed that this granite-schist complex, when traced southward into the Felch Mountain district and northward into the Republic district, rested unconformably below the Huronian. The indefinite age and scattered occurrence of the southern conglomerates have been cited, and previous discussion indicates that the conglomerate at Republic contains no granite pebbles and boulders and actually is older than the surrounding granite. Hence some other means of correlation should be sought.

At present, correlation appears to be chiefly a matter of the most logical and reasonable interpretation based on such facts as are available. These facts are: (1) dikes cutting, and intrusive contacts with, the Huronian formations; (2) the relation of contact metamorphism to the granite periphery, as shown by the character of outcrops near the granite in comparison with those some distance from it and by the persistence of magnetic attraction where the iron-formation is near the granite; (3) the general similarity of accessory minerals obtained from parts of the granite with known and unknown relations to the Huronian, including post-Huronian granite of the Crystal Falls district, and the relation of these minerals to additive ones occurring in the metamorphosed Huronian rocks; (4) similarity of primary structures in various parts of the granite, apparently having consistent relationships to the regional structure if the granite were intruded during orogenic disturbance of the Huronian rocks (Fig. 1); (5) similarity of mineralogy throughout the granite and also its similarity to some Killarney granites,[54] a fact which has been suggested as a possible criterion of similar age;[55] and (6) very limited and scattered occurrence of conglomerates containing granitic debris, the age of such conglomerates being indefinite. With the exception of the conglomerates, these facts all indicate the same interpretation, namely, the existence of a post-Huronian granitic unit of large extent. Indeed, the conglomerates, because of their very limited and scattered occurrence, might indicate the same interpretation if they contain fragments of a Huronian or a pre-

[54] W. H. Collins, "North Shore of Lake Huron," *Can. Geol. Surv. Mem. 143* (1925), pp. 86–87.

[55] F. F. Grout, "Ages and Differentiation Series of the Batholiths near the Minnesota-Ontario Boundary," *Geol. Soc. Amer. Bull. 40* (1929), pp. 791–809.

Huronian granite, but our present knowledge of these conglomerates is deemed to be too meager to warrant any such interpretation.

CONCLUSIONS

It is the writer's belief that there is sufficient evidence to warrant the conclusion that the northern part of the Southern Complex, extending from about 5 miles west of Republic to at least 3 miles east of Palmer, is in reality a post-Huronian granitic unit to which the name "Republic granite" is applicable, as the term "Southern Complex" implies a pre-Huronian basement on which the Huronian formations were deposited. Moreover, it is believed that the post-Huronian granite included in the southern part of the Southern Complex correlates with this northern post-Huronian granite and that much of the granite of the Southern Complex is really of post-Huronian age and forms a mass of batholithic proportions with large areal extent.

It is believed that many features otherwise difficult to explain may fit well into the regional picture if one adopts this concept of the Republic granite. (1) The extensive contact metamorphism which persistently follows the periphery of the Southern Complex is difficult to explain except on the basis of intrusion of batholithic extent. (2) The remarkable similarity of accessory minerals from widely separated specimens of granite, some intrusive into Huronian rocks, others showing no definite relation, is difficult to explain if the granite is not essentially a unit. Moreover, the fact that certain additive metamorphic minerals observed in Huronian rocks are also present in the accessories obtained from the granite is difficult to explain if the greater part of the granite is of Archean age. (3) Petrographic similarity of granite from widely separated parts of the area and similarity to Crystal Falls post-Huronian granite also indicate unity. Differences of texture between dikes and small intrusives and the main granite mass cause no difficulty but accord well with the concept of a batholithic mass and its associated pegmatites and aplites. (4) Primary structures of granite, although obviously showing some local variation, yield the same general structural pattern for the region as a whole and indicate intrusion under forces directed from the northeast and the southwest, accounting for the westward

projection of a tongue of granite in the Lake Michigamme area. (5) Deformation in places around the margins of the granite appears to be a normal phenomenon and is easily explained as a result of early marginal solidification followed by subsequent orogenic movement during the same period of orogeny and intrusion. Such deformation as exists within the granite mass may well be due to later diastrophism, as most people familiar with the Lake Superior region would hesitate to state that the Killarnean was the last time of deformation. (6) Keewatin schists and gneisses and Huronian rocks occupy a normal and logical position if the major mass of granite is of post-Huronian age, and it is not necessary to postulate a series of highly fortuitous occurrences to explain their position.[56] (7) Some conglomerates have been shown to be of pregranite age and to have been metamorphosed by the granite, fitting them and their structural features into the picture. Others at the present time apparently have unknown relations to Huronian rocks and the granite and cannot be made to fit into any regional picture.

From a regional viewpoint, the writer believes that the concept of the Republic granite more nearly satisfies all observed field relations than the concept of the Southern Complex. However, regardless of the writer's opinion, it is hoped that the foregoing survey of this problem may serve some useful purpose and be a step toward orderly progress in unraveling the problems of the Lake Superior region, many of which are as yet unsolved.

[56] Dickey, *op. cit.*, pp. 322–23.

THE CRANIAL MORPHOLOGY OF A NEW GORGONOPSIAN

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ABSTRACT

Cyonosaurus longiceps gen. et sp. nov., a gorgonopsian from the *Cistecephalus* zone of the Karroo Series, South Africa, is described and figured. The excellent state of preservation of the skull and lower jaws has revealed many important features of structure heretofore unknown or little understood. In the description particular stress is laid upon the details of the inside of the brain case and the otic region.

INTRODUCTION

In the collection of Karroo vertebrates of Walker Museum is an excellently preserved specimen of a rather small gorgonopsian consisting of skull and lower jaws. A small portion of the snout has been damaged by weathering, and the shape has been somewhat altered by lateral compression. There is, however, little difficulty in restoring the original shape of the skull by a study of the amount of compression suffered by the palate. The sutures are filled, for the most part, by a gray matrix and can be distinguished with ease.

Great pains have been taken in the preparation of this unusual specimen. To facilitate the removal of the matrix surrounding the internal structures two sections have been made. One passes vertically at right angles to the axial plane back of the postorbital bar, and the other cuts the posterior part of the skull in the vertical axial plane just to the right of the midline. Most of the preparatory work has been carried on under a 30-power magnifying glass. As a result it is possible to make out much of the detailed structure. Of particular interest are the internal features of the osseous portions of the brain case.

FAMILY GORGONOPSIDAE

CYONOSAURUS, NEW GENUS

GENOTYPE.—CYONOSAURUS LONGICEPS

Diagnosis.—Skull approximately as high as wide. Pineal opening rather large, set in raised, oval area. Preparietal large, roughly diamond shaped. Maxillary large with very short subjugular process.

Parietal and frontal extended only slightly ventrad to form lateral walls of brain case. Epipterygoid free from contact with parietal. Notch for cranial nerve V and notch for vein in proötic shallow and not enclosed by bone anteriorly.

Angular process on lower jaw small.

CYONOSAURUS LONGICEPS, NEW SPECIES

Holotype.—University of Chicago, No. 1515. Skull and lower jaws.

Horizon and locality.—Lower *Cistecephalus* zone. Toverwater farm and few miles southeast of Murraysburg, South Africa.

Diagnosis.—Length of skull, 148 mm. Height at level of postorbital bar, 25 mm. Maximum height (most ventral point on quadrate to most dorsal point of skull just anterior to orbit), 53 mm. Width (estimated from compression of palate), 55 mm.

Upper dental formula: incisors, 4; canines, 1; molars, 7. Lower dental formula: incisors, 3(?); canines, 1; molars, 8. Incisors large. Molars very small. Canines long and recurved, uppers larger than lowers.

DESCRIPTION OF SKULL

The descriptions of certain of the superficial bones of the skull are omitted in the following pages since their structure is apparent in Plate I and Figure 4. These bones, namely, nasals, premaxillaries, maxillaries, prefrontals, postfrontals, postorbitals, dermo-supraoccipitals, and jugals, are essentially similar to those in other normal gorgonopsians. The bones which are described either differ somewhat from those in other gorgonopsians or yield information on structures heretofore unknown or little understood.

Frontals.—The frontals are broad, roughly diamond-shaped bones in contact with the nasals, prefrontals, orbits, and postfrontals along the lateral margins. They are separated posteriorly in the midline by the preparietal and the parietals. On the inside of the skull (Fig. 1) the frontals are well exposed. Their lateral margins project ventrally to form lateral walls of a shallow trough. This trough is continued posteriorly by the parietals and will be described in more detail in connection with these bones.

Each frontal has a small foramen on the medial margin of the

lateral, ventral ridge. These foramina do not reach the surface of the skull and presumably were for nutrient vessels.

Preparietal.—The preparietal is a diamond-shaped bone with irregular margins. It lies between the posterior processes of the frontals and the anterior projections of the parietals. On the inside of the skull this bone forms a small part of the roof of the brain case anterior to the pineal opening. It extends a short distance down along the lateral ridges formed by the frontals and parietals (Fig. 1).

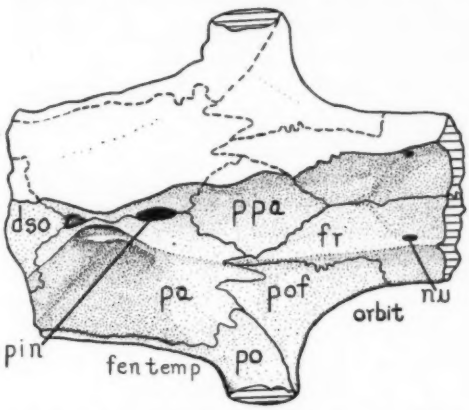


FIG. 1.—Under side of skull roof of *Cyonosaurus longiceps* in region of orbit and temporal fossa. ×1. *dso*, dermo-supra-occipital; *fen temp*, fenestra temporalis; *fr*, frontal; *nu*, nutrient fossa; *pa*, parietal; *pin*, pineal opening; *po*, postorbital; *pof*, postfrontal; *ppa*, preparietal.

The bone is somewhat more restricted in area on the inside of the skull than on the outside.

Parietals.—The parietals form the posterior portion of the horizontal roof of the skull and pass a short distance onto the sloping occipital region. They are in contact with the frontals and postorbitals along the lateral margins and the dermo-supraoccipital and tabulars along the posterior margin. The pineal opening lies in the midline between the parietals on a slightly raised, ovoid area.

On the inside of the skull the parietals are somewhat more broadly exposed, underlying the medial margin of the postorbitals and the posterior portions of the postfrontals. However, the anterior parts

of the parietals are underlain by the frontals. The pineal opening on the under surface of the roof of the skull is somewhat longer than it is on the outer surface. The parietals, with the frontals, form two pronounced ridges which pass forward from the level of the pineal opening to the anterior margins of the orbits. Between these ridges is a trough-like depression which presumably housed the dorsal part of the anterior portion of the brain. The trough is about 3 mm. deep, 6 mm. wide just anterior to the pineal opening, and 13 mm. wide at the level of the anterior margins of the orbits.

Lateral to each main ridge on the parietals, running forward from the dermo-supraoccipital to the level of the anterior margin of the pineal opening, is a second smaller ridge. It forms a much smaller trough on the outer slope of each large ridge. The function of this trough is obscure.

Lacrimals.—The lacrimals are small, rectangular bones in contact with the maxillaries anteriorly, the jugals ventrally, the postfrontals dorsally, and the orbits posteriorly. Each lacrimal contains two small foramina on the orbital margin. The ventral foramen is large and the dorsal one small. Although there seems to be no previous record of such a condition in the gorgonopsians, the arrangement is similar to that in various cynodonts. The openings appear to represent the foramina lacrimalia and presumably unite anterior to their external openings to form a single lacrimal canal as they do in the cynodonts.

Squamosals.—The squamosals are large, complex bones. Each forms the posterior part of the bar beneath one of the temporal openings. It swings around to form the posterior margin and about one-third of the median dorsal margin of the temporal opening. Along the inner portion of the temporal opening the squamosal is in contact with the tabular medially and the postorbital anteriorly. The median portion of the bone is very thick and underlies a considerable part of the sloping occipital region of the skull. It is overlain by the tabular and dermo-supraoccipital in this position and is not exposed on the upper surface of the occiput. Both the proötic and opisthotic are strongly attached to the deep medial part of the squamosal. The quadrate and quadratojugal are closely applied to the anterior face of the posterior part of the squamosal and project a short distance below it to form the articulation with the lower jaw.

Basioccipital.—The basioccipital forms much of the posterior part of the basicranium. It is joined to the basisphenoid on the outer surface of the brain case by a suture. On the inside, however, this suture opens into a broad unossified area which extends between the basioccipital and basisphenoid very nearly to the outer surface of the basicranium. This unossified area passes forward through the posterior wall of the sella turcica and at this point separates the basioccipital from the proötic as well as from the basisphenoid.

No suture is present between the basioccipital and the opisthotic. The line of junction of these two bones is indicated by the position of the jugular foramen which passes laterally and somewhat ventrally out of the brain case to the surface of the skull. The dorsal margin of this opening is made up of the supraoccipital, the anterior margin by the opisthotic, and the ventral and posterior margins by the basioccipital. Posterior to the jugular foramen is a smaller opening which passes laterally from the brain case and opens to the surface of the skull immediately back of the jugular foramen. It presumably was for cranial nerve XII.

Opisthotic.—The opisthotic, which is joined without suture to the basioccipital, passes laterally below the rather large post-temporal fenestra to meet the squamosal. Medial to the fenestra, it is in contact with the supraoccipital and presumably the exoccipital, although the exact limits of the latter cannot be determined since no suture is present separating it from the basioccipital. The opisthotic joins the proötic with no suture, and it is impossible to be certain of the exact line of contact.

The dorsal and anterior rims of the fenestra ovalis are formed by the opisthotic and perhaps in part by the proötic. The ventral portion of this fenestra is formed by the basioccipital. The fenestra ovalis is located on the side of the basicranium, and immediately above it is a smaller, elongate opening which passes from the vestibule of the inner ear just above the stapes to the middle ear. The function of this foramen is as yet uncertain.

Proötic.—The proötic is a relatively large bone which plays an important part in the formation of the lateral walls and the floor of the brain case. Its relationships to the other bones of the brain case, the structures of the inner ear, and the foramina of the cranial nerves are complex.

Considering the proötic first as it appears on the inside of the brain case, the structure is as follows. Anterior to the basioccipital, the proötic forms a portion of the floor of the brain case. This part of the bone is separated from the basioccipital by the unossified area mentioned above. The proötic passes forward to form a roof over about half of the sella turcica. Laterally the junction of the proötic and the basisphenoid is marked by a suture.

The posterior portion of the proötic floor of the brain case extends laterally to form the anterior margin of the vestibular cavity. Just anterior to this cavity a small foramen passes laterally through the proötic to the exterior surface of the skull. This is interpreted as the exit for both the palatine and hyomandibular branches of the facial nerve. Lying dorsal to this foramen is the anterior termination of the horizontal semicircular canal. This canal lies partly in the proötic and partly in the opisthotic, passing back to a point just in front of the jugular foramen. The median wall is not ossified, but presumably it was covered by cartilage during the life of the animal. Anterior and posterior ampullae lay at the respective ends of this canal. The course of the posterior vertical canal cannot be traced. The anterior vertical canal passes around the subarcuate fossa in the same position which it occupies in the cynodonts.

The relationship of the proötic and the supraoccipital on the inner side of the brain case is quite complex. In effect the supraoccipital has grown down in a process over the proötic to form a portion of the lateral wall of the brain case between fossa of the endolymphatic duct and the subarcuate fossa. It also lies on the side of the brain case posterior to the proötic and opisthotic making up a part of the foramen magnum. The suture between the proötic and supraoccipital, which is well defined, passes back from the anterior margin of the brain case, along the angle between the roof and side, to the level of the subarcuate fossa. It enters the fossa on its dorso-anterior margin and reappears on the dorso-ventral margin swinging forward for a short distance and then curving sharply down and back to enter the dorso-anterior rim of the horizontal semicircular canal. It emerges on the dorsal margin of the canal just below the fossa of the endolymphatic duct and, passing through this fossa, continues to the roof of the skull. The section of the brain case cut

along the midline shows that this suture very nearly reaches the dorsal surface of the occipital region and then makes a sharp angle back and down to emerge again on the inside of the brain case as the posterior suture between the opisthotic and supraoccipital. It then swings in an arc down into the jugular foramen where it disappears.

As a result of the arrangement described above, both the proötic and supraoccipital play an important part in the formation of the inside of the lateral and dorsal walls of the brain case. The supraoccipital is exposed on the outer surface of the occipital region, and the proötic forms nearly the entire outer surface of the lateral wall of the brain case. Both bones play an important part in the formation of the deep subarcuate fossa and the fossa of the endolymphatic duct which lies posterior and slightly dorsal to the subarcuate fossa.

The anterior margin of the proötic is free. Near its base is a shallow incisure for nerve $V^{2,3}$. Above this incisure is a shallow notch which was venous in nature.

In outer aspect the proötic shows several interesting features. It makes up a major part of the lateral surface of the brain case. Posteriorly it is in contact with the squamosal, from which it is separated by a suture, and with the opisthotic, to which it is fused. Dorsally it is in contact with a narrow strip of the supraoccipital which, in turn, lies immediately below the dermo-supraoccipital. The base of the proötic is in contact with the basisphenoid, from which it is separated by a faint but distinct suture. The opening for the facial nerve emerges near the posterior margin of the proötic. Below it is a deep pit, presumably for the geniculate ganglion. Running forward from the foramen is a shallow groove which leads along the side of the brain case. Obstructing the path of this groove there is a very thin septum, unfortunately damaged in preparation subsequent to its exposure. This ridge runs from the base of the proötic incisure down onto the basisphenoid. It is pierced by two small foramina, one dorsal and one ventral. The groove on the side of the brain case passes to the ventral foramen. Probably the inferior branch of the nerve went through the lower opening and the superior branch passed through the upper one.

Supraoccipital.—The condition of the supraoccipital on the inside

of the brain case has already been indicated in the discussion of the proötic. It forms much of the roof of the brain case and passes down inside of the proötic to the horizontal semicircular canal in an area lying between the subarcuate fossa and the fossa of the endolymphatic duct. Posteriorly it passes down the side of the brain case to form the anterior portion of the jugular foramen and the dorso-lateral margins of the foramen magnum.

The supraoccipital is widely exposed on the dorsal surface of the occipital region, lying posterior to the dermo-supraoccipital. Sections of this part of the skull show that this bone is overlapped by the dermo-supraoccipital anteriorly and the tabular laterally.

On the outer lateral surface of the brain case the supraoccipital is exposed as a narrow strip wedged between the dermo-supraoccipital above and the proötic below.

Basisphenoid and parasphenoid.—The basisphenoid and parasphenoid are fused together, as in all gorgonopsians, in such a way that it is impossible to distinguish one from the other. The posterior portion of the complex represents the basisphenoid and the anterior the parasphenoid, but the exact limits of the bones cannot be determined.

The relationships of the basisphenoid and the basioccipital have been described in connection with the latter. These bones are in actual contact only along their ventral and lateral margins, the other portions being separated by an unossified area. The proötic rests on the dorsal margin of the basisphenoid, from which it is separated by a suture.

The sella turcica lies in the basisphenoid, its base and lateral walls being formed by this bone. The floor is divided into lateral halves by a median septum which rises a short distance above the floor. Each half contains two small depressions, one anterior and one posterior. Anterior to these depressions, in the floor of the sella, there is a shallow, cuplike depression, and anterior to this a gentle dorsal extension of the bone forming the anterior margin.

The basipterygoid process of the basisphenoid projects laterally a short distance to come in contact with the pterygoid. At the anterior end of the process there is an opening passing from the ventral surface of the brain case into the cranial cavity just in front of the

sella turcica. The exact nature of this opening cannot be determined in the specimen. It may be a foramen for the internal carotid artery, but this conclusion is tentative.

The ventral surface of the basisphenoid does not differ markedly from that described in other gorgonopsians. Posteriorly it is joined to the basioccipital by a well-defined suture. The posterior tubera are well developed but small in comparison to those in such forms as *Scymnognathus*.[1] A median keel passes forward from the tubera and merges with the keel of the parasphenoid.

The parasphenoid forms the anterior portion of the complex. It continues forward to the point at which the pterygoids join in the midline and wedges in between these two bones. This junction, which is quite clearly shown by sutures, lies just back of the transverse processes of the pterygoids. The parasphenoid possesses both a median dorsal and a median ventral keel.

Quadrate and quadratojugal.—The quadrate and quadratojugal are small bones which are closely applied to the anterior surface of the squamosal on the posterior rim of the temporal opening. They are set in a depressed area on this bone and extend for about one-third of their length below its ventral margin.

The quadrate is the larger and lies on the inside of the quadratojugal. It has a broad contact with the dorsal portion of the opisthotic process medially. Its base forms the articulation with the lower jaw. The condyle, which extends onto the posterior surface of the bone, is very small, and the articulation with the lower jaw must have been very weak.

The quadratojugal is a small bone lying lateral to the quadrate. It is closely applied to the latter, but the two appear to be separated by a faint suture. Lying in this suture, just below the margin of the squamosal, is the quadrate foramen. The quadratojugal seems to have formed a part of the articulation of the skull with the lower jaw.

Stapes.—The stapes is a very large bone in this form as in all gorgonopsia. It possesses a large stapedial foot which is inserted in the irregular fenestra ovalis. Lateral to the foot is the stapedial

[1] D. M. S. Watson, "The Bases of Classification of the Theriodonta," *Proc. Zoöl. Soc. London* (1921), pp. 35–98.

foramen enclosed above and below by narrow bands of bone. Lateral to the foramen, the stapes consists of a narrow, bladelike process which extends out to the inner margin of the quadrate. At its termination there is a rather deep depression between the quadrate and the posterior portion of the opisthotic process. This presumably housed part of the tympanic membrane.

Epipterygoids.—The epipterygoids, while essentially normal in structure, possess several interesting features. Most striking, perhaps, is the lack of connection between the basal and ascending processes of this bone. Presumably these two parts were joined by cartilage during the life of the animal, although there is no definite evidence to support such a contention. The dorsal surface of the basal process is composed of smooth, finished bone, and the ascending ramus tapers to a ventral point. The lack of connection between these parts in the present specimen suggests that there were two centers of ossification of the epipterygoid in at least some of the gorgonopsians. Neither of the ascending rami was found exactly in their normal location in the specimen. The right ramus had fallen back over the ventral part of the proötic, and the left had shifted somewhat forward.

A second feature of importance is that the ascending rami have smooth, rounded dorsal margins. There was no connection to the parietal. This condition is similar to that in *Lycaenodon*, figured by Broom[2] and Boonstra.[3] It is quite different from that in such forms as *Scymnognathus* and *Leptotrachelus*.[4]

A third point of interest lies in the fact that the basal process of the epipterygoid extends back of the basipterygoid process of the basisphenoid as a free, winglike process for about 12 mm. and reaches within 3 mm. of the quadrate. It is difficult to compare this condition with that in other gorgonopsians since the epipterygoid is seldom well preserved. Boonstra[5] has figured the bone in a number of

[2] R. Broom, "On the Structure of the Mammal-like Reptiles of the Suborder Gorgonopsia," *Philos. Trans. London*, Series B, Vol. CCXVIII (1930), pp. 345–71.

[3] L. D. Boonstra, "Additions to Our Knowledge of the South African Gorgonopsians Preserved in the British Museum," *Ann. S. African Mus.*, Vol. XXXI (1935), pp 175–213.

[4] Watson, *op. cit.*

[5] *Op. cit.*

genera, and in no case is the process like that in *Cyonosaurus*. In every case, in these figures, the outlines of the epipterygoid are broken, implying that the bone is either reconstructed or but poorly preserved. This use of broken lines, even in cases in which the text indicates that the bone is present and well preserved, makes it difficult for the reader to be certain about the condition of preservation, the nature, and even the presence of the bone. Broom's sections of

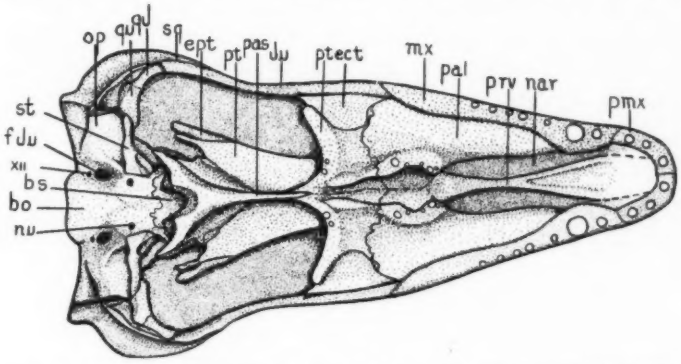


FIG. 2.—Palate of *Cyonosaurus longiceps*. ×⅔. Restored to apparent original width. *bo*, basioccipital; *bs*, basisphenoid; *ect*, ectopterygoid; *ept*, epipterygoid; *f ju*, jugular foramen; *ju*, jugal; *mx*, maxillary; *nar*, internal naris; *nu*, nutrient fossa; *op*, opisthotic; *pal*, palatine; *pas*, parasphenoid; *prv*, prevomer; *pt*, pterygoid; *qj*, quadratojugal; *qu*, quadrate; *pmx*, premaxillary; *sq*, squamosal; *st*, stapes; *XII*, foramen for cranial nerve XII.

Cynaroides[6] indicate that the posterior wing of the epipterygoid in this form was not nearly so well developed as in *Cyonosaurus*.

Pterygoids.—The pterygoids do not differ greatly from those in other genera of gorgonopsians. The quadrate rami, which lack the posterior extremities, are closely applied to the rostrum of the parasphenoid and articulate with the flat basipterygoid process of the basisphenoid. They taper posteriorly and presumably passed back to the quadrate. Each transverse process bears two large teeth near the midline. Anteriorly the pterygoids are closely applied together, extending 15 mm. forward to their junction with the palatines. On either side of the midline is a small ridge, forming a portion of one

[6] *Op. cit.*

wall of the median groove. Anterior to the transverse processes the lateral portions of the pterygoids are underlain by the ectopterygoids.

Ectopterygoids.—The ectopterygoids are small bones which lie anterior and lateral to the transverse processes of the pterygoids. Almost the entire dorsal surface of each of these bones is applied to the ventral surface of the corresponding pterygoid in such a way that the palate in this region is composed of two layers of bone.

Palatines.—The palatines are long, rather narrow bones which extend forward from their sutural junction with the pterygoids to form the lateral margins of the internal nares. The palatal groove is carried forward on the palatines to the level of the posterior termination of the internal nares. Its lateral walls are formed by strong, tooth-bearing ridges. No sutures are visible between the two palatines or between the palatines and the prevomers in spite of the fact that these bones are clearly exposed.

The internal nares, bounded laterally by the palatines and medially by the prevomers, are situated rather high in the skull, lying considerably above the contact of the palatines and maxillaries. This gives the anterior portion of the palate a distinctly vaulted character. In the anterior pterygoidal region the vaulting is reversed, and the ventral portions of the pterygoids lie somewhat below the margins of the jugals. The palatal groove passes from the vaulted palatine area, just back of the internal nares, to a point just anterior to the transverse processes of the pterygoids. There seems to be little doubt that it acted as a conduit for air from the internal nares to the anterior part of the throat. Quite probably the groove was covered ventrally by a membrane, forming a functional soft palate.

Prevomer.—The prevomer is a long, slender bone passing from the anterior end of the palatal groove to the premaxillaries and forming the median margins of the internal nares. It bears low lateral ridges but no median keel. The anterior end has not been exposed, and the relationships to the premaxillaries has not been determined.

DESCRIPTION OF THE LOWER JAW

The structure of the lower jaw of *Cyonosaurus* is typically gorgonopsian and differs only in various details from that of other genera. The main features are apparent in the accompanying figures which are composites based on information obtained from a study of both jaws.

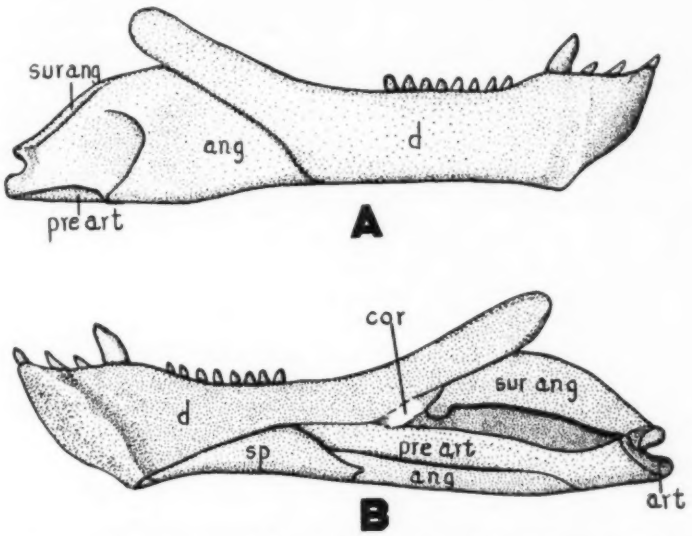


FIG. 3.—Lower jaw, right, of *Cyonosaurus longiceps*. ×¾. *A*, outer aspect; *B*, inner aspect. Composite reconstructed from both right and left jaws. *ang*, angular; *art*, articular; *cor*, coronoid; *d*, dentary; *pre art*, prearticular; *sur ang*, surangular.

The dentary, which is broadly exposed on both the inner and outer surfaces of the jaw, is the largest element present. The dorsoposterior portion of the bone is extended into a slender "coronoid" process. The dental formula of the lower jaw is: incisors, 3(?); canine, 1; molars, 8. An interesting feature of the dentition is shown in one of the incisors in which two germs of developing teeth underlie the erupted tooth. At least two replacements were present in these anterior teeth.

The angular forms most of the posterior third of the outer surface

of the jaw and, about 18 mm. in front of the posterior tip of the jaw, passes onto the ventral and inner surface, enclosing the basal portion of the prearticular. It continues forward to the dentary on the outer surface and to the splenial on the ventral and inner surfaces.

The prearticular is a large bone exposed mainly on the inner surface of the jaw but also appearing along the ventral margin of the external surface beneath the posterior part of the angular. It is in contact with the articular posteriorly, the angular ventrally, and the coronoid and dentary antero-dorsally. Its dorsal margin forms the ventral rim of the meckelian orifice.

The surangular lies above the meckelian orifice on the inner side of the jaw and is exposed along the dorsal margin of the outer surface above the angular.

The coronoid was somewhat damaged by the lateral compression of the jaws which forced it against the transverse process of the pterygoid. Its posterior end appears to be in the original position between the surangular and the dentary. The anterior end lies between the dentary and the prearticular.

The splenial is a large bone exposed only on the inner side of the jaw. It is in contact with the angular and prearticular posteriorly and the dentary dorsally. The anterior extremity forms a small part of the symphysis, most of which is on the dentary.

DISCUSSION

In the study of the skull and jaws of *Cyonosaurus* many interesting problems of morphology and comparative anatomy have arisen. The present paper is largely descriptive. Subsequent papers, now in preparation, will deal with the comparative cranial morphology of the gorgonopsians and related groups.

PLATE I

PHOTOGRAPHS OF SKULL OF *Cyonosaurus longiceps*. ×¾. *A*, RIGHT LATERAL ASPECT; *B*, DORSAL ASPECT

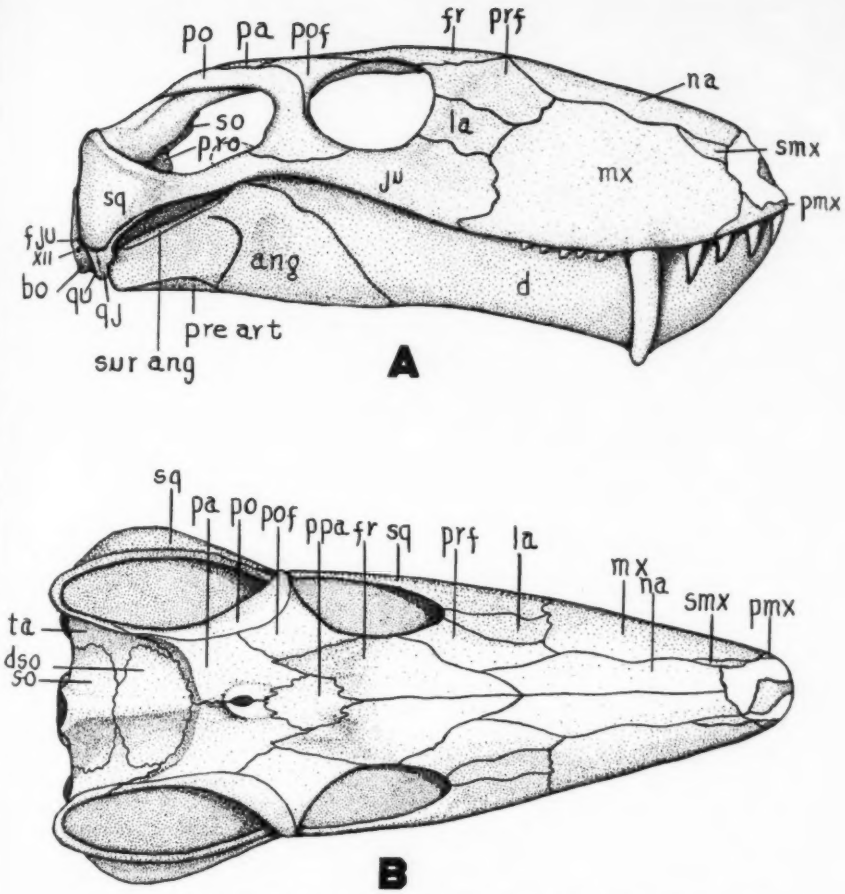
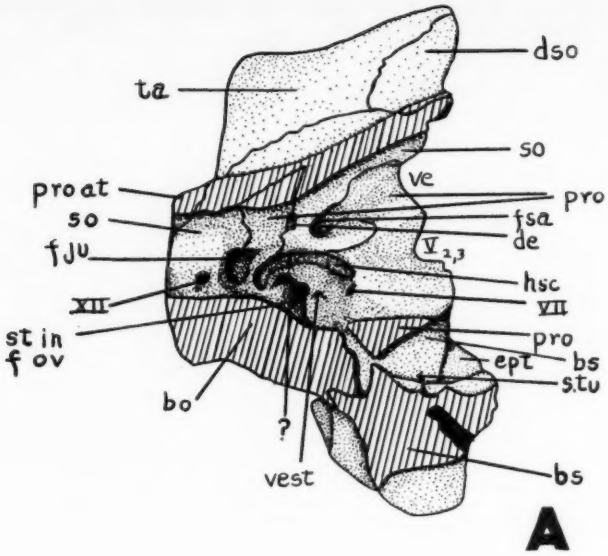


FIG. 4.—Drawings of skull of *Cyonosaurus longiceps*. *A*, right lateral aspect; *B*, dorsal aspect, restored to apparent original width.

The abbreviations used in all the plates and figures are as follows: *ang*, angular; *bo*, basi-occipital; *bs*, basisphenoid; *d*, dentary; *de*, fossa of endolymphatic duct; *dso*, dermo-supra-occipital; *ept*, epipterygoid; *f ju*, jugular foramen; *f m*, foramen magnum; *f p t*, posttemporal foramen; *f qu*, quadrate foramen; *fr*, frontal; *f sa*, subarcuate fossa; *f st*, stapedial foramen; *ge*, geniculate ganglion; *h s c*, horizontal semicircular canal; *ju*, jugal; *la*, lacrimal; *mx*, maxillary; *na*, nasal; *op*, opisthotic; *pa*, parietal; *pmx*, premaxillary; *po*, postorbital; *pf*, postfrontal; *ppa*, preparietal; *pre art*, prearticular; *prf*, prefrontal; *pro at*, proatlas; *pro*, proötic; *pt*, pterygoid; *qu*, quadrate; *qj*, quadratojugal; *smx*, septomaxillary; *so*, supra-occipital; *sq*, squamosal; *st*, stapes; *st in for ov*, stapes in foramen ovalis; *s tu*, sella turcica; *sur ang*, sur-angular; *ta*, tabular; *ve*, venous notch; *vest*, vestibule; $V^{2,3}$, notch for branch 2 and 3 of cranial nerve V; *VII*, foramen for cranial nerve VII; *XII*, foramen for cranial nerve XII.



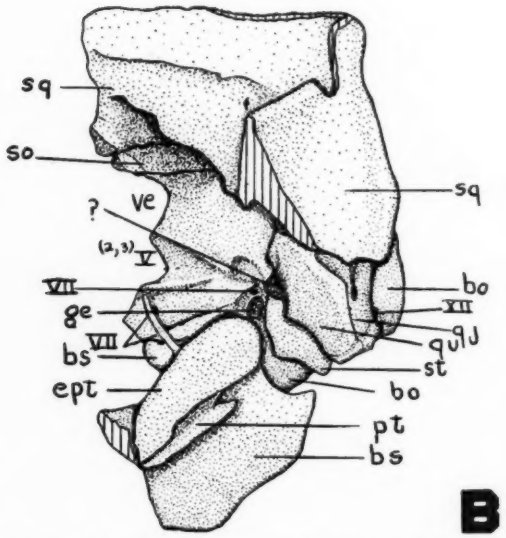
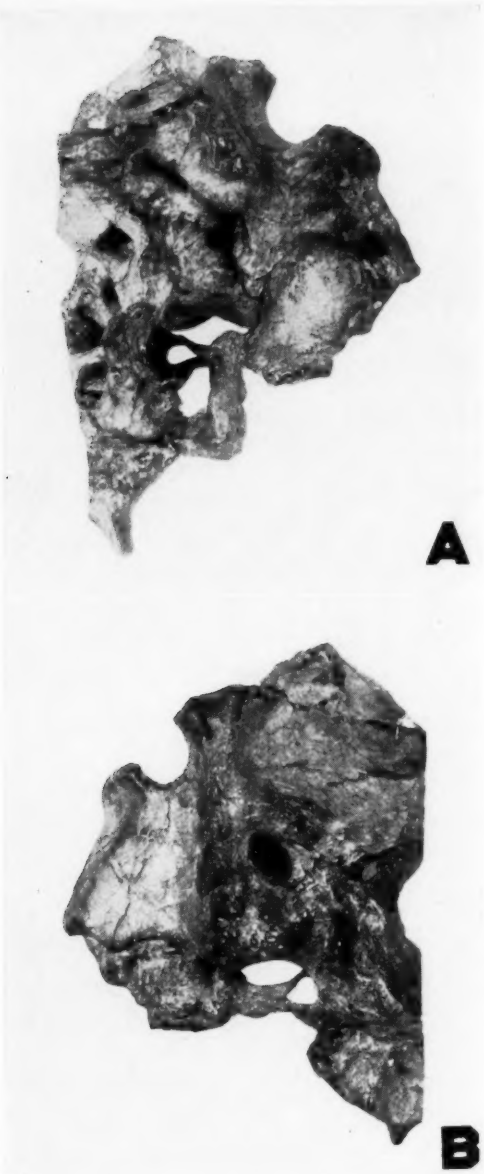


FIG. 5.—Drawings of left half of posterior part of brain case of *Cyonosaurus longiceps*. ×1½. *A* and *B* as in Plate II.

PLATE II

PHOTOGRAPHS OF LEFT HALF OF POSTERIOR PART OF BRAIN CASE OF *Cyonosaurus longiceps*. ×1½. *A*, INNER ASPECT FROM RIGHT SIDE OF SKULL; *B*, OUTER ASPECT.

PLATE III



PHOTOGRAPHS OF POSTERIOR PART OF SKULL OF *Cyonosaurus longiceps*. ×1¼. *A*, LEFT HALF OF BRAIN CASE AND TEMPORAL REGION FROM FRONT; *B*, OCCIPITAL REGION FROM POSTERIOR.

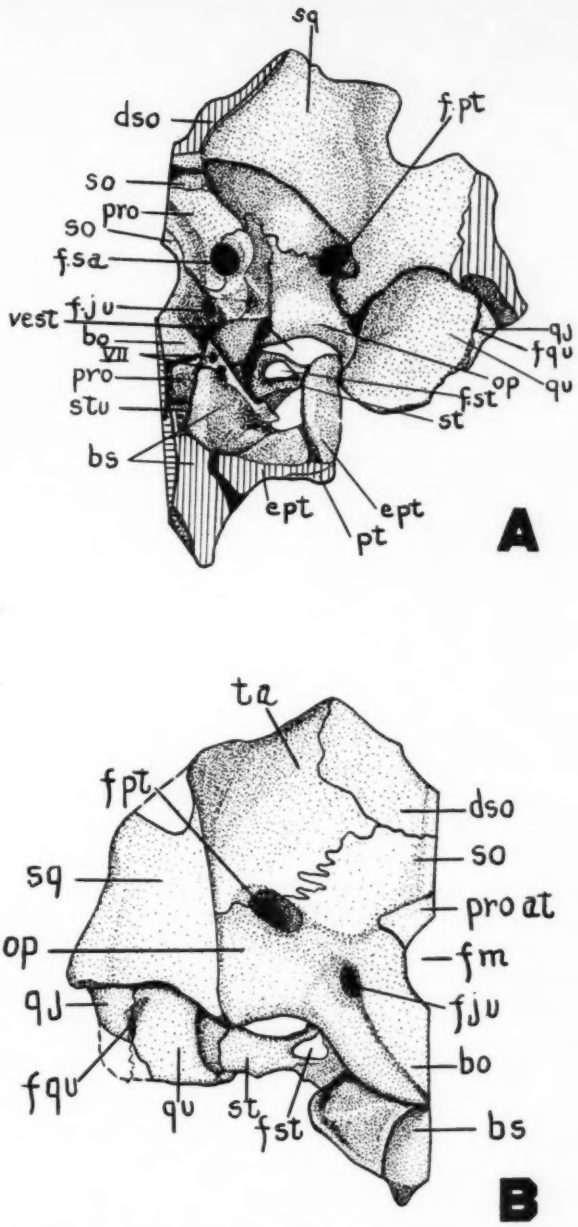


FIG. 6.—Drawings of posterior part of skull of *Cyonosaurus longiceps*. ×1½. *A* and *B* as in Plate III.

A DICOTYLEDONOUS FLORULE FROM THE TRINITY GROUP OF TEXAS

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ABSTRACT

Imprints of leaves of dicotyledonous plants appear in the Paluxy sands of Erath County, Texas. Three species only have so far been recognized, a *Cinnamomum*, a *Sapindopsis*, and an *Araliaephyllum*. The last named form is remarkable for its highly developed structure and for its variability.

INTRODUCTION

Erath County, Texas, lies not far from the geographic center of the state. Stephenville, its county seat, is about 70 miles southwest of Fort Worth and 100 miles northwest of Waco. Almost the whole of the county lies in the great belt of the Comanchean, or Lower Cretaceous, which sweeps around the Llano uplift and passes northward across the state to the Red River. Its northern borders lie directly upon the old rocks of the Pennsylvanian, while farther to the east and south are spread out the vast Black Lands of the Upper Cretaceous.

Most of the surface rock of the county belongs to the Trinity division composing the lowermost Comanchean of this region. Two formations are represented, the Paluxy sand and the locally underlying Glen Rose limestone, which are "facies of one continuously and laterally changing mass of sediments."[1] In general, these formations have been held to correspond to the Upper Aptian and Lower Albian of Europe. Gayle Scott,[2] however, states that "the Paluxy Sand is unquestionably Middle Albian." If the statement quoted from Adkins is correct, the Glen Rose must also be of Middle Albian age.

FOSSIL LEAVES FROM THE PALUXY SANDS

About 7 miles to the northwest of Stephenville is a rather conspicuous rounded knoll, on the western slope of which lies the farm

[1] W. S. Adkins, "Geology of Texas," Vol. I, *Univ. Texas, Bur. Econ. Geol. Bull. 3232*, Part II (1932).

[2] Letter to C. L. Baker, October 20, 1936.

of Mr. F. H. Cook. About 100 yards below the farm house is a "gall" or small area of land from which the better top soil has been eroded. This tract is not more than 40 by 60 feet in extent. The soil is red in color and consists largely of a sandy clay containing lenticular clay-ironstone nodules, having a characteristic mammilated surface. Many of these nodules when split are found to contain beautiful imprints of leaves of dicotyledonous flowering plants. Mr. Cook informed me that he has been collecting these fossils at intervals, for more than twenty years.

I first saw some of the specimens in the display at the Centennial Exposition of the University of Texas at Austin, which is in charge of Dr. H. B. Stenzel. Dr. Stenzel informed me of their origin and I am profoundly indebted to him for his generosity in allowing me the opportunity to describe them. He placed his entire collection, consisting of fifteen items, at my disposition. Some of them are shown in Figures 2–6.

I immediately visited Mr. Cook and he, also, very generously allowed me to use such as I wished from the remainder of his collection. One specimen, however, that shown in Figure 1, the most complete and beautiful of the group, was found after Dr. Stenzel's visit by Mrs. E. V. Walton, a daughter of Mr. Cook. From other sources I have obtained three other specimens which had been loaned or given away by Mr. Cook.

Dr. Robert T. Hill was good enough to interest himself very actively in the finds. Although thoroughly familiar with the geology of Erath County, Dr. Hill made a special visit to Mr. Cook's farm to review the terrain and he assures me that the horizon from which the fossils came is beyond doubt the Paluxy sand. He advises me, however, that he has moved the Paluxy from the top of the Trinity division to the base of the succeeding Fredericksburg, and that he bases this change largely on the presence of the dicotyledons in the Paluxy. The Paluxy is, therefore, well dated, since it is both preceded and followed by limestones bearing characteristic invertebrate fossils.

There are some forty-five items in the collection, four of five of which are indeterminable. Of those forms that can be identified with reasonable certainty, one seems to be an imprint of a *Cin-*

namomum, one of a *Sapindus*, and the remainder, though differing greatly among themselves, appear to be an ancestral or composite form of such plants as are now designated by the names *Aralia*, *Sassafras*, *Benzoin*, *Sterculia*, *Artocarpus*, *Acer*, and the like. Their great variability renders description a difficult matter.

The pattern set by the veins of some of these very ancient leaves is astonishingly complex and modern in aspect. One constantly has the feeling that he is looking at fossils as young at least as those of the Dakota sandstone, or of its equivalent, the Woodbine of the Gulf States. This high specialization at so early a date indicates that the history of the dicotyledons had already been a very long one.

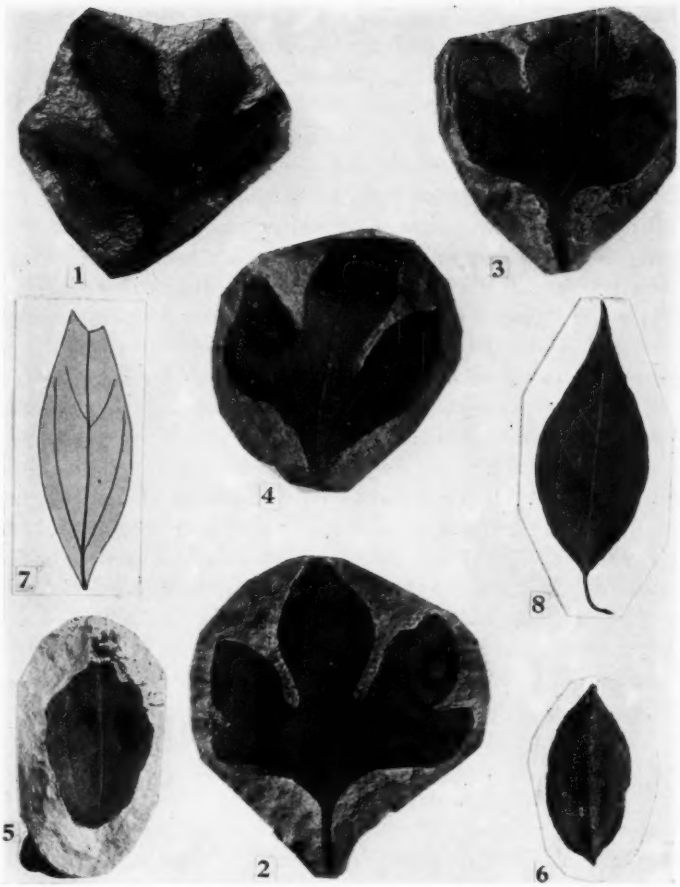
The nearest dicotyledons in the geologic time table are those of the Potomac series. In 1889,[3] Fontaine published his epoch-making monograph in which, for the first time, dicotyledonous plants from a date as early as the Lower Cretaceous (Comanchean) were described. They were from the Patapsco formation, at the top of the Potomac column, a narrow bed of sands and clay, extending from Richmond, Virginia, northward through Maryland into New Jersey. From this formation, Professor Fontaine described seventy-four named species of angiosperms, in twenty-nine genera, all of which are dicotyledons. In naming new genera he, in general, followed the custom of the still earlier paleobotanists of Europe in using terms indicative of what appeared to be their nearest living affinities. I shall follow his example.

THE FLORULE

Order Umbellales; Family Araliaceae; Genus *Araliaephyllum* Fontaine; *Araliaephyllum paluxyense* Ball, n.sp. (Figs. 1–4)

Leaves, three- or four-lobed, or the right and left segments of a three-lobed leaf may each bear a small lobe, making the leaf apparently five-lobed, by a digitate division of the veins of the petiole, the divisions occurring at different levels at or near the uniformly cuneate base, but the sinuses extend not more than halfway into the lamina. The middle lobe is distinctly larger than its companions,

[3] W. M. Fontaine, "The Potomac or Younger Mesozoic Flora," *U.S. Geol. Surv. Mono. 15* (1889).



FIGS. 1–8.—FIG. 1, *Araliaephyllum paluxyense* Ball, n.sp., paratype, showing venation; FIG. 2, *Araliaephyllum paluxyense* Ball, n.sp., paratype, showing maximum size; FIG. 3, *Araliaephyllum paluxyense* Ball, n.sp., paratype, showing stout venation; FIG. 4, *Araliaephyllum paluxyense* Ball, n.sp., paratype, showing thinner venation; FIG. 5, *Cinnamomum paluxyense* Ball, n.sp., type specimen; FIG. 6, *Sapindopsis cooki* Ball, n.sp., type specimen; FIG. 7, *Cinnamomum newberryi* Berry, from Woodbine at Arthurs Bluff, Texas; FIG. 8, *Cinnamomum camphora* Nees et Eberm. Extant, introduced for comparison.

and is obcordate, rounded, or narrowed gradually upward to a more or less acuminate apex; margins entire, decurrent on the petiole, which is short and generally curved. The leaf substance was evidently heavy and leathery.

The leaves vary from 5×5 cm. in the smaller sizes up to about 9×10 cm. in the larger. Most of them are three-lobed (Figs. 3, 4), a few five-lobed (Fig. 2), and a single one (Fig. 1) is four-lobed.

Although the leaves vary so greatly in form, the pattern of their venation is strikingly uniform; there is a stout midrib arising from the petiole and to its right and left, at slightly different levels, a thick lateral primary (Fig. 3). Each of these passes into and ends in the tip of a lobe. Each lateral primary gives rise to a lateral secondary, which extends into a secondary lobule, if one is present.

The secondary venation consists of five or six generally unpaired, thick veins, which arise at angles of from 35° to 45° from their primaries, arch irregularly upward, and become camptodrome along the margins. A characteristic feature of the secondary venation (Fig. 1) is seen in the inosculation of two secondaries into a stout, straight vein which passes on to the sinus, but just before reaching the fundus, divides into a U-shaped structure, the arms of which pass up along the margins of the sinus. The tertiary venation consists of numerous short and thick veins, set at angles of about 45°; some of them are percurrent between the secondaries. Little can be seen of the nervilles of the fourth order. The particularly fine leaf of Figure 1 appears to show a finely reticulated surface of quadrangular areolae.

Figure 3 shows a trilobate leaf which could be compared with *Araliaephyllum aceroides* Fontaine,[4] in which the shape and venation are identical. The only difference is that the latter leaf seems to be about twice as large as any specimen in the Cook collection; the leaf in Figure 1 may be compared to *A. acutilobum* Fontaine.[5] They are of similar size and shape and the lobes are equally pointed at their apexes.

Fontaine has four species of *Araliaephyllum*, all coming from the same restricted area of the Potomac near Brooke, Virginia, at the 72d mile-post. One-fourth of a mile north of this exposure, which is

[4] *Ibid.*, p. 319, Pl. CLVI, Fig. 2.

[5] *Ibid.*, Pl. CLXIII, Fig. 2.

in a railroad cut, another outcrop contains no *Araliaephyllum* whatever. Fontaine, indeed, expressly states that the lithological character of the two exposures is markedly different.

The leaf shown in our Figure 3 might very readily be called *A. crassinerve* (Fontaine) Berry, since it differs from the latter in no essential respect except size. Fontaine described a fine leaf as *Platanophyllum crassinerve*, which was later transferred to *A. crassinerve* by Berry; at the same time he combined *A. acutilobum* Fontaine and *A. obtusilobum* Fontaine, very correctly, as I believe, with the same species. His judgment is fully sustained by the multiplicity of variants in the Cook collection. Berry[6] states that these forms "undoubtedly represent the ancestral form of *Aralia newberryi* Berry,[7] a common Upper Cretaceous species." This may be true, yet there is little in common between the Paluxy species and the figures showing the supposedly later forms. They have a similar multiple nervature and lobation but so far as I am able to determine from photographic material, the leaves from Erath County show a much more highly developed nerve pattern than those from the Patapsco. From the same beds, Fontaine[8] described *Aceriphyllum araliodes* and *Hederaephylum angullatum*. These were removed by Berry to the genus *Araliaephyllum*, species *magnifolium* Fontaine. All three variants can be seen, I believe, in the Cook collection. In short, the multiplicity of forms shows that we have to do with a comprehensive type, one having leaves of widely differing shapes. This variability was emphasized by Berry.[9]

On the other hand, the Glen Rose beds contain a small flora of about twenty-three species[10] most of which were described by Fontaine. Nine of these appear in the Patapsco and twelve are "identical with or closely related to plants from the lower Potomac so that a strong presumption of the nearness of age of the two formations is established."[11] The Glen Rose florule contains no

[6] E. W. Berry, "Lower Cretaceous," *Maryland Geol. Surv. 1* (1912), p. 491.

[7] E. W. Berry, *Bull. Torr. Bot. Club*, Vol. XXXIV (1907), p. 201.

[8] *Op. cit.*, p. 489.

[9] E. W. Berry, "Lower Cretaceous," *Maryland Geol. Surv.* (1912), p. 490, Pl. XCV, Fig. 1.

[10] W. M. Fontaine, *Proc. Natl. Mus.*, Vol. XVI (1893), p. 261. [11] *Ibid.*

dicotyledons, yet the Patapsco florule, as revised by Knowlton,[12] has some forty species. It appears to the writer, therefore, that the Paluxy cannot be of age equivalent to the Glen Rose, but that a hiatus of greater or less extent exists between the two. Another indication of the existence of such a gap is the strikingly modern aspect of the species found at Cook's farm, which regrettably are only three in number.

Occurrence.—Paluxy sands, Erath County, Texas, about 7 miles northwest of Stephenville; collected by F. H. Cook. Type specimens in collection of the University of Texas. Co-types Collection of the A. and M. College of Texas. No. 2117.

Order Thymeleales; Family Lauraceae; Genus *Cinnamomnm* (Burm.) R. Brown; *Cinnamomum Paluxyense* Ball, n.sp. (Fig. 5)

Leaf, in life probably about 7 cm. long, including the petiole, and 2.5 cm. wide, elliptical in outline, widest near the middle. Margins entire, base narrowing to a petiole about 2 cm. long, which is still covered by the matrix and appears as a tail-like appendage. The apical region is lost.

Midrib rather prominent, flanked on each side by a lateral primary. These arise near the base at slightly different levels and follow the general contour of the margins, incurving in the apical regions and forming a graceful, narrow, elliptical figure with the midrib as the long axis. The secondary nervation cannot be seen clearly, though there are indications that the midrib may have borne two or more secondaries high up in the leaf.

There does not appear to be any reason to doubt the propriety of placing this leaf in the genus *Cinnamomum*. The genus does not occur in the Patapsco of Fontaine and was not recorded by Berry in his revision of the Potomac flora[13] but a near relative, *Sassafras*, is found in the Raritan and Magothy formations of the Upper Cretaceous, though there is but one species;[14] in this the triple nervation is like that of our specimen.

[12] F. H. Knowlton, "Catalog of Mesozoic and Cenozoic Plants of North America," *U.S. Geol. Surv. Bull. 696* (1916), p. 707.

[13] E. W. Berry, "Lower Cretaceous," *Maryland Geol. Surv.* (1916), p. 483.

[14] *Ibid.*, p. 860, Pl. LXXI, Fig. 6.

Leaves of this type occur in Cretaceous formations in many parts of America and are very widespread in the Tertiary of America, Europe, and even of Australia. Such forms are usually placed by paleobotanists in the genera *Cinnamomum* and *Daphnogene* of the Lauraceae. Our leaf bears a very close resemblance to some of the many variations of the well-known *C. scheuchzeri* Heer,[15] from the Tertiary of Switzerland, and to *C. dubium* Watelet[16] and *Daphnogene pedunculata* Watelet,[17] from the Eocene of the Paris Basin.

From the Woodbine at Arthurs Bluff on the Red River,[18] in Lamar County, Texas, Berry describes *C. newberryi* (Fig. 7), a leaf evidently closely related to the Paluxy specimen. However, it has no petiole and the midrib bears a pair of short but distinct secondaries in its upper third. Berry[19] gives an extensive synonymy for this species and its vast geographical distribution and wide range in the Upper Cretaceous.

Knowlton[20] in Hill's monumental work on the Black and Grand prairies of Texas, recorded *C. ellipsoideum* Saporta and Marion from material collected by G. H. Ragsdale from Woodbine, Cooke County, Texas. He states that "its identification is absolute." From Rhameys Hill[21] near Denison, Texas, T. V. Munson collected *C. heeri* Lesquereux, both of which are common in the Dakota sands. Among the specimens from Cooke County, Knowlton mentions *Cinnamomum* n.sp. (?) "fragments that do not seem to belong to any described species." Both *C. ellipsoideum* and *C. heeri* usually have a rounded base, but in some specimens of *C. heeri*[22] the basal region

[15] O. Heer, *Flora tertiaria Helvetiae*, Vol. II (Winterthur, Germany: J. Wurster et Cie, 1856), p. 85, Pl. XCI, Figs. 2–24.

[16] Ad. Watelet, *Plantes fossiles du Bassin de Paris* (Paris: J. B. Bailliers, 1886), p. 175, Pl. L, Fig. 4.

[17] *Ibid.*, Fig. 8.

[18] E. W. Berry, "Flora Woodbine Sand," *U.S. Geol. Surv. Prof. Paper 129G* (1921), p. 173.

[19] *Ibid.*

[20] F. H. Knowlton in R. T. Hill's *Geography and Geology of Black and Grand Prairies* (1901), p. 317.

[21] *Ibid.*, p. 318.

[22] J. S. Newberry, "Later Ext. Floras, North America," *U.S. Geol. Surv. Bull. 35* (1898), p. 100, Pl. XVII, Fig. 1.

is like that of *C. paluxyense* and there are no secondaries. Of the six species of *Cinnamomum* appearing in the Dakota sands, still another, *C. marioni* Lesquereux,[23] appears also to be very close to our leaf, but differs sharply in having a double set of lateral primaries.

Some of the much younger forms from the Tertiary are strangely like this oldest of all from Erath County. For example, *Daphnogene cinnamomeifolia* Unger[24] from the Eocene of Sotzka, in Styria, is identical with *C. paluxyense* except that it is about twice as large, while *C. rossmaessleri* Heer from Tertiary formations at Dux, in northern Bohemia, cannot be distinguished from the Texas leaf except that it has no petiole, which may be an accident.

From the Wilcox group of Henderson County, Texas, the writer has described[25] *C. pre-camphora* Ball, which, like the fossil forms *C. ellipsoideum* and *C. heeri*, and the extant *C. camphora* Nees and Eberm. has a rounded base. A photograph of a small and young variant leaf of the last named is introduced in Fig. 8 for comparison. Most of the leaves of this species have full, rounded bases, but many are just as markedly cuneate as the leaf figured, which comes from a camphor tree growing in a garden near Houston, Texas. It will be noted that the secondaries are few and small and that there is an evident petiole. *C. paluxyense* differs from this leaf in no essential respect, since traces of secondary veins appear in the fossil.

Occurrence.—Paluxy sands, Erath County, Texas; about 7 miles northwest of Stephenville; collected by F. H. Cook; type specimens in collection of the University of Texas.

Order Sapindales; Family Sapindaceae; Genus *Sapindopsis* Fontaine; (?) *Sapindopsis cooki* Ball, n.sp. (Fig. 6)

Leaflet(?), elliptical in shape, slightly falcate and inequilateral, although the latter condition may be due to infolding of the margins, 4.5 cm. long, apiculate; margins full and entire; leaf substance and epidermis apparently thick and heavy, perhaps subcoriaceous; sur-

[23] L. Lesquereux, "Flora of the Dakota Group," *U.S. Geol. Surv. Mono. 17* (1892), p. 105, Pl. LI, Figs. 6, 7.

[24] E. Engelhardt, *Tert. Flora v. Dux* (Dresden, Germany: Blochmann und Sohn, 1891), p. 167, Pl. XI, Fig. 1.

[25] O. M. Ball, "Contrib. Palebot. Eoc. Texas," *Bull. Agr. & Mech. College of Texas, No. 5* (4th ser., 1931).

face finely and irregularly lined and roughened. The midrib is stout and prominent. Nothing definite can be distinguished as to the secondary venation, which in any case would have been indistinct in a leaf of such heavy texture. It would manifestly be hazardous to assert a definite allocation for a leaf having so poorly defined characters.

The slight deviations from regularity in contour of this fossil lead me to conjecture that it represents a leaflet belonging to some pinnately divided leaf. We may compare it with *Sapindopsis brevifolia* Fontaine,[26] although it must be admitted that there does not seem to be any convincing similarity.

Occurrence.—Paluxy sands, Erath County, Texas, about 7 miles northwest of Stephenville; collected by F. H. Cook; collection of the University of Texas. Type specimen.

The very "modern" aspect of the leaves from Erath County is impressive. At the opening of the long Cretaceous period, when the land was yet filled with hordes of dinosaurs, the flowering plants, as shown by these three species, had already passed through a long developmental history, and in their leaves, at least, had established a form and structure from which they never afterward departed.

The three species, if their identification is valid, belong to three widely different orders of plants of world-wide distribution, containing great numbers of genera and species. Such conditions seem also to indicate a phylogenetic history of enormous length. The fluctuations shown by *Araliaephyllum paluxyense* may indeed be held to indicate a mobility due to youth; yet even then, the origin of the angiosperms could hardly have been later than the early Mesozoic.

[26] W. M. Fontaine, "Younger Mesozoic Flora," *U.S. Geol. Surv. Mono. 15* (1889), p. 300, Pl. CLIII, Fig. 4; Pl. CLV, Fig. 1.

THE TOREVA-BLOCK—A DISTINCTIVE LANDSLIDE TYPE

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ABSTRACT

An end member of the "rock-slide" group is described and named from an assigned type locality in the Hopi Indian Reservation of northeastern Arizona. A Toreva-block consists essentially of an unbroken tilted mass of stratified material which in numerous instances measures over 1,000 feet along the strike. Attempt is made to relate the slides to pediment remnants at the type locality. Distribution and character of Toreva-blocks elsewhere in the Colorado Plateau Province are briefly discussed. Available data suggest the late Pleistocene formation of the larger slides.

INTRODUCTION

The following notes call attention to a kind of landslide which is widely distributed in the southern part of the Colorado Plateau Province, and which has been, in the past, an important factor in cliff recession. For this type of slide the name "Toreva-block" is proposed because of its splendid development near Toreva, in the Hopi Indian Reservation of Arizona. Most of the observations reported were made in the fall of 1934. They have been extended from time to time since, as opportunity offered. That they are here set forth is due in large part to the insistent encouragement of Professor Kirk Bryan, who visited the Toreva district with the writer in July, 1936.

CHARACTER AND CLASSIFICATION

A Toreva-block is a landslide consisting essentially of a single large mass of unjostled material which, during descent, has undergone a backward rotation toward the parent cliff about a horizontal axis which roughly parallels it. In the southern Colorado Plateau such blocks have developed from cliffed sections of low-dipping strata in which one or more relatively coherent beds rest upon others which are either incoherent or capable of so becoming when wetted.

According to Heim's classification[1] Toreva-blocks are *Felsstürtze* rather than *Felsschlipfe*, the latter being characterized by motion

[1] A. Heim, *Über Bergstürtze* (Zurich, 1882). Quoted by E. Howe.

along valleyward-dipping bedding planes. According to Howe's scheme[2] they constitute end members of the rock-slide group.

While none of Howe's photographs suggest the sort of slide discussed, it is clear from his text[3] that the Yellow Mountain and Sheep Mountain slides of the Telluride district approach the simplicity of form of what are here termed Toreva-blocks.

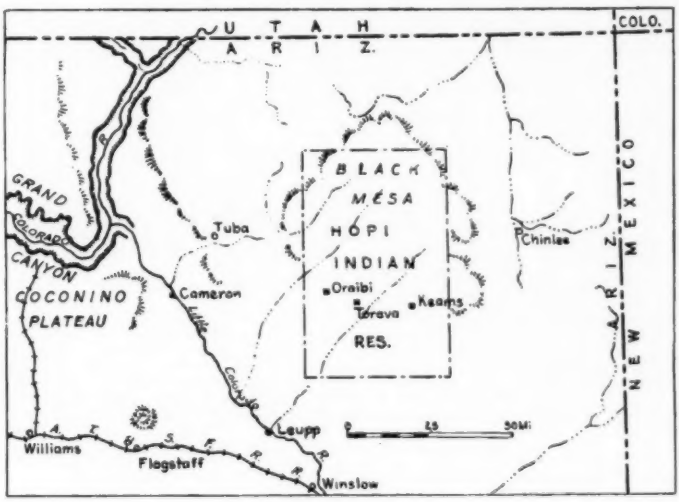

FIG. 1.—Index map

The slides described by Russell[4] in the Cascade Mountains closely resemble those under consideration, although the outcrops do not, apparently, permit detailed observation. The blocks, consisting of 400 to 500 feet of basalt resting on "clays and sands, or on volcanic lapillae . . . . are seldom over a half mile in length" and their component strata are stated to dip 10 to 15 degrees toward the parent cliff.[5]

[2] E. Howe, "Landslides in the San Juan Mountains of Colorado," *U.S. Geol. Surv. Prof. Paper 67* (1909), p. 55.

[3] *Ibid.*, pp. 19–20.

[4] I. C. Russell, "Cascade Mountains in Northern Washington," *U.S. Geol. Surv. 20th Ann. Rept.*, Part II (1898–99), pp. 193–200.

[5] *Ibid.*, p. 196.

GEOLOGIC SETTING OF THE TOREVA DISTRICT

The Toreva district lies midway of the deeply embayed southern margin of Black Mesa, which, according to Gregory[6] ". . . . is the center of a broad and shallow structural basin. . . . . " The Mesa is floored by sandstones and shales of the Mesaverde formation, upper Cretaceous. Of this only the lower 170 feet, including 77 feet of cliffed, basal soft sandstone, is present near Toreva. Underlying the Mesaverde is the Mancos shale, also upper Cretaceous, dominantly of grey, soft, fissile, silty shale with a local thickness[7] in excess of 295 feet. These formations dip 3°–4° northerly.

FIG. 2.—Section of a Toreva-block exposed by stream cut at the type locality. The block lies on the upper pediment, seen in profile at left. Its base is emphasized by a sheep trail.

The cliffed lower sandstone of the Mesaverde is obscurely cross-bedded and is interrupted by approximately vertical joints. Near the mesa point (Fig. 3) these are fairly closely spaced and strike between N. 13° E. and N. 64° E.; southwest of Mishongnovi they are widespaced and trend N. 30° W. Throughout the district joints and cliffs show a rough parallelism and not infrequent rapid change in direction. These relations suggest that the jointing is chiefly superficial, consequent on the removal of lateral support by canyon cutting and cliff recession.

[6] H. E. Gregory, "Geology of the Navajo Country," *U.S. Geol. Surv. Prof. Paper 93* (1917), p. 112.

[7] *Ibid.*, p. 74.

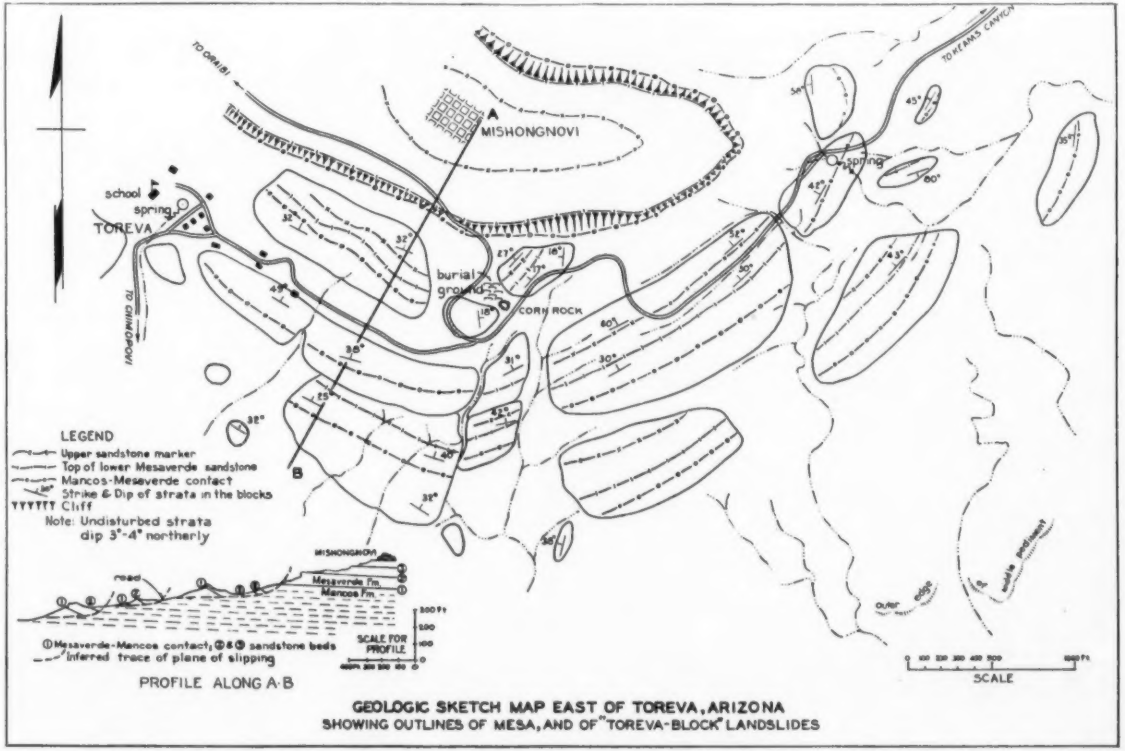
TO ORAIBI
TO KEAMS CANYON
MISHONGNOVI
A
B
school
spring
TOREVA
TO CHIMOPOVI
burial ground
CORN ROCK
spring
LEGEND
Upper sandstone marker
Top of lower Mesaverde sandstone
Mancos-Mesaverde contact
Strike & Dip of strata in the blocks
Cliff
Note: Undisturbed strata dip 3°-4° northerly
MISHONGNOVI
road
Mesaverde Fm.
Mancos Fm.
SCALE FOR PROFILE
①Mesaverde-Mancos contact; ②&③ sandstone beds
Inferred trace of plane of slipping
PROFILE ALONG A-B
SCALE
GEOLOGIC SKETCH MAP EAST OF TOREVA, ARIZONA
SHOWING OUTLINES OF MESA, AND OF "TOREVA-BLOCK" LANDSLIDES

FIG. 3

THE LANDSLIDES

In his excellent reconnaissance study Gregory wrote:

> Landslides . . . . occur at the sites of the Hopi villages. . . . . The Cretaceous strata forming the mesa dip south and the prominent saturated zone at the top of the Mancos shale favors the sliding of insecure blocks of the overlying Mesaverde sandstones. Sections of the cliffs at Shimopovi are found 1,000 feet from their original position. That the process has been long continued is indicated by gradations in the degree of decomposition of the fallen masses and by the traditions of the Hopis. In recent years slides have occurred at times when ground water was present in unusual amounts.[8]

While one might infer from Gregory's description that these are *Felsschlipfe* in Heim's sense, owing their mobility to the plane of weakness offered by the top of the Mancos shale, such is not the case. The local dip of the formations is northerly and so slight that this surface is not important as a plane of slipping; and the outwardly concave fractures on which movement takes place cut obliquely across the upper Mancos, part of which, therefore, moves and is rotated with the block. Only the lowermost 5–15 feet of the displaced material is found crushed and jostled. The vertical displacements (70–220 ft.) are not as impressive as the size of the blocks: nearly a quarter have strike lengths of 1,100 feet or more; occasional blocks exceed 1,700 feet. In places successive slides have occurred from the same stretch of cliff, building up step fashion below it to a profile in which further slides would have to cut or displace pre-existing ones. As suggested by Gregory, the slides farther removed from the present cliffs are in general clearly the older. In places disintegration has proceeded so far as to make the slide nature of ridges conjectural.

The general form of the rarely seen slip planes underlying Toreva-blocks, as inferred from a study of numerous examples, is shown in Figures 3 and 6. As illustrated in Figure 5, the cliffward portion of a block often shows a steeper dip than the outer portions. In the instance sketched erosion has left only a remnant of a large block, and has entirely destroyed the parent mesa-point. The tendency of the strata to preserve their initial angle with the plane of fracture throughout movement was interfered with b[illegible] by frictional re-

[8] *Ibid.*, p. 136.

FIG. 4.—View down strike valley cut in the largest Toreva-block at type locality

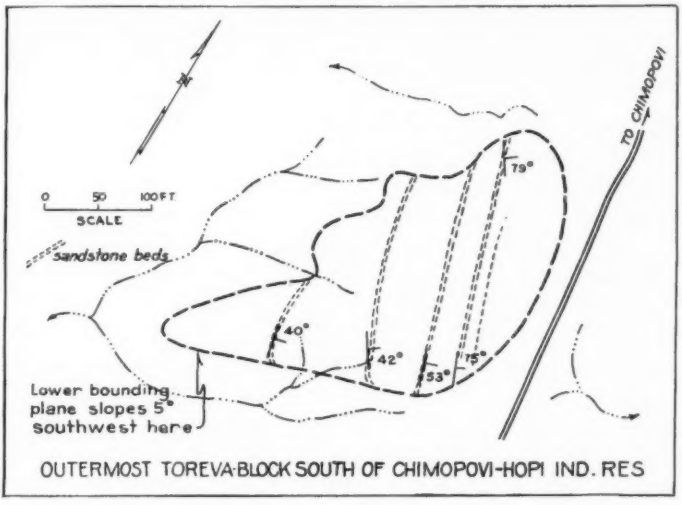

FIG. 5.—Erosion remnant of Toreva-block south of Chimopovi (2 miles southwest of Toreva), Hopi Indian Reservation, Arizona.

sistance on the plane of slipping and by the greatly diminished curvature of the lower part of that surface. The result was, as shown, a sort of fanning out of the beds.

The fact that no extensive catchment area of mesa-top was necessary to provide moisture for lubrication of the plane of slippage is

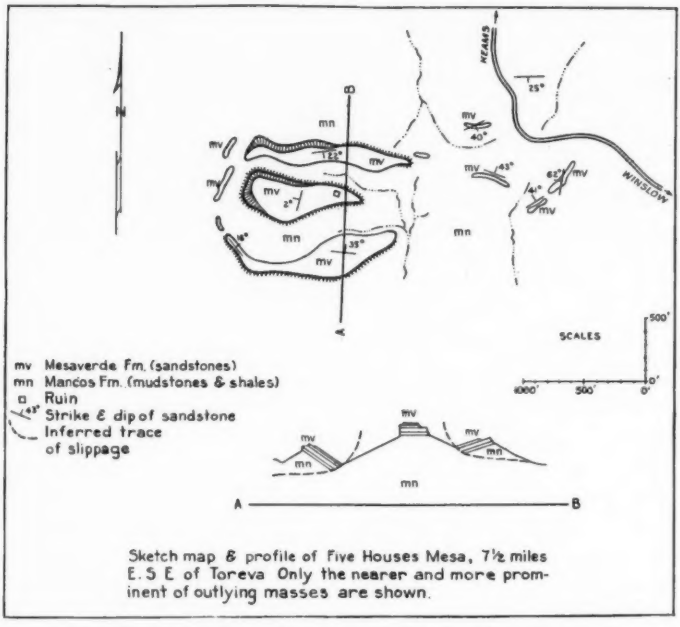
N
mv Mesaverde Fm. (sandstones)
mn Mancos Fm. (mudstones & shales)
Ruin
Strike & dip of sandstone
Inferred trace of slippage
SCALES
1000' 500' 0'
500'
0'
A
B
Sketch map & profile of Five Houses Mesa, 7½ miles E. S E. of Toreva. Only the nearer and more prominent of outlying masses are shown.

FIG. 6.—Geologic sketch map and profile of Five Houses Mesa, 7½ miles east-southeast of Toreva, Hopi Indian Reservation, Arizona.

shown by the observations recorded in Figure 6, in which only the inner and more prominent of the Toreva-blocks have been drawn. The width of mesa, at the time the final slide took place, can scarcely have exceeded 700 feet (see section *AB*, Fig. 6). Similar or even smaller dimensions are indicated for the final stages of a former mesa remnant near the bend in the road in the northeast part of the area shown in the same figure. The former existence of this mesa remnant is attested by five partly destroyed inward-dipping Toreva-blocks.

What may be the initial stage in the splitting off of another block

was noted about 1,000 feet east of Mishongnovi, where 5 feet of debris from a cliffed slope mantle the top of the "lower sandstone." A sink-hole in the debris has formed over a 10-inch fissure in the sandstone.

ASSOCIATED LAND FORMS AT THE TYPE LOCALITY

The surfaces on which the landslides came to rest are generally obscured. Because of their possible bearing on the time and conditions of maximum sliding, brief account is made of local morphology.

Near Toreva two early erosion surfaces, or pediments, slope toward the Polacca Wash and its tributaries. These surfaces have been almost completely destroyed by the headward extension of a third, whose thalweg has been trenched 30–50 feet by the Polacca Wash during the past half-century. The early pediments are represented by small remnants, trenched by gulches graded to the lowest surface; the recent incision of Polacca Wash has not as yet affected the mapped area.

The upper and middle pediments differ in elevation by 10–30 feet; the middle and lower by 50–65 feet. All have surface slopes of 3.5–5.5 in a hundred. East of the south-central part of the area sketched (Fig. 3) they are obscured by wind-blown sand.

Any attempt to tie the Toreva-block formation to the period of development of one or more of the pediments runs into an immediate difficulty: Chronologically the blocks that are lowest and outermost, with respect to the mesa outlines, were formed before those that are highest and innermost. Precisely the reverse order is true for the pediments. These circumstances make it progressively less possible for blocks to reach later pediments. A given slide is clearly younger than the surface on which it is found, but the time interval between the formation of that surface and the descent of the slide cannot in general be estimated.

Numerous Toreva-blocks rest upon both of the upper pediment surfaces. Several small outer slides appear to have come to rest in gulches cut into the middle pediment. As these are, perforce, among the oldest of the slides, it follows that most of those now identifiable postdate the completion and partial destruction of the second pediment. They thus fall within the period during which the lowest pediment was formed.

An interesting condition a half-mile east of Chimopovi[9] was called to the writer's attention in the field by Professor Kirk Bryan. For a distance along the strike of 90 feet Mancos shale has been shoved about 15 feet over the blow-sand filling of an old gulch. The latter had been cut into the uppermost pediment about 12 feet by a northward-flowing stream. The shove was from the west, in which direction the Mancos shale involved dips of 1°–3°. Whether this mass of disturbed shale is the toe of a Toreva-block or was merely pushed forward by such a toe is not determinable, due to outcrop discontinuity. The upper few inches of the blow-sand have been weakly cemented (lime) and preserve crude slickensides. The stage of erosion of the displaced shale mass suggests a relative antiquity both for the slide and for effective Quaternary wind action in this district.

TOREVA-BLOCKS OF OTHER DISTRICTS

As previously noted, the type of landslide under discussion is widely distributed in the southern part of the Colorado Plateau and at other contacts than that between the Mesaverde and the Mancos formations. To cite only a few examples:

Toreva-blocks are present in several tributary canyons of the Colorado in the Grand Canyon district, according to observations made by W. H. Swayne. The largest are stated[10] to occur in the Thunder River Canyon (near Tapeats Creek) and in the lower valley of Chuar Creek. In both places the blocks comprise part of the Redwall limestone, the Muav limestone, and the Bright Angel shale. In Surprise Valley in the Thunder River Canyon district, Mr. Swayne found slides 1,700 to more than 2,000 feet in length, measured along the strike. In the Chuar Creek examples, Carbon Butte, a slide mass about three-quarters of a mile in diameter, is pre-eminent. From the description afforded by Mr. Swayne it seems probable that the parent cliff has receded about 4 miles and the shape of the block greatly changed since the displacement.

Numerous examples occur along the San Jose and Rio Colorado drainages in and near the Laguna Indian Reservation of New Mexico. The strata involved are the sandstones of the lower Mancos

[9] Indian pueblo about 2 miles southwest of Toreva. Spelled also Shimopovi, Shungopovi, etc., etc.

[10] Letter to the writer, January 13, 1937.

and the Dakota formations and the shaley beds of the upper Morrison, which outcrop in the walls of the Rio San Jose canyon, and the Todilto limestone, Wingate sandstone, and upper Chinle shales appearing in the cliffs on the northwest side of the Rio Colorado valley. One example, 7 miles south and slightly east of Old Laguna, seems to have been mistaken for part of a fold and to have occasioned an oil prospect. The landslide mass measures about 550 feet along the strike, and the disturbed beds have dips as high as 50 degrees; the vertical displacement is approximately 175 feet. Erosion subsequent to sliding has caused retreat of the parent cliffs by more than 2,000 feet.

In many places, though the stratigraphy, jointing, and relief seem favorable for their production, Toreva-blocks are absent. Along the Book Cliffs of Utah and Colorado and the western rim of Mesaverde in southwestern Colorado, in both of which the Mancos-Mesaverde formation contact is conspicuous, this type of slide is either missing or extremely rare. The same is true of the northern and eastern faces of Black Mesa in the Navajo country.

Their destruction by later active pedimentation may be responsible for the absence of Toreva-blocks in many places. In others, as in Mesaverde, the coherent upper member appears deficient in strength due to shaley interbeds. Dips above a few degrees and a too-close spacing of joints are probably prohibitive of this type of sliding. Thus Toreva-blocks are present, although rare, along the Vermilion Cliffs, but absent along the Echo Cliffs monocline in Arizona.

AGE OF TOREVA-BLOCK FORMATION

Throughout the region it appears that most of the Toreva-blocks date back a thousand to many thousands of years. Near Chimopovi ruins of thirteenth- and fourteenth-century pueblos occur along the crests of the two largest and nearly the last-formed slides.[11] A similar condition was noted east of Mishongnovi. The mesa-foot springs below both these villages are doubtless largely responsible for the intermittent Indian occupation of the district for the past thousand years or more. These springs owe their existence to the dipslope surface and subsurface drainage of Toreva-blocks, which is sufficient

[11] L. L. Hargrave, "Shungopovi," *Mus. Notes, Mus. Northern Ariz.*, Vol. II, No. 10 (1930).

to insure their permanence. The extent to which streams have dissected the blocks and have been adjusted to their differentially resistant beds testifies even more emphatically to the antiquity of the process.

Two poor examples of Toreva-blocks are known to have formed in historic times. Both involve the Mancos-Mesaverde contact. One, about 250 feet long, lies back of Chimopovi Day School and dropped about 1870. It is stated to have caused a local quake and the drying up of the old walled spring. While dropping about 60 feet, with maximum rotation of 14°, it broke into several pieces, now standing at different levels. The other known recent slide is said to have occasioned a slight quake in 1927[12] at a place 43 miles northeast of Toreva, some 6 miles north of Black Mountain Store. The block, about 300 feet long, dropped 60 feet and tilted to 45°. It cracked into numerous angular fragments which, however, were not jostled.

That a more humid climate than the present would have been conducive to the production of Toreva-blocks, by moistening and lubrication of their relatively incoherent underpinnings, seems evident. The effects of the Pleistocene climatic regime were certainly marked in the region discussed. The writer has observed evidence of nivation along the top of the Chuska Mountains, about 160 miles east of Toreva and 2,000 feet or so higher; and the probably Wisconsin alpine glaciation of San Francisco Peaks 115 miles to the southwest has been made familiar by the work of Robinson.[13] That some late Pleistocene or post-Pleistocene climatic regime was responsible for the production of the majority of the Toreva-blocks seems not unlikely. A conspicuously wet climatic episode is believed[14] to have occurred during the first millenium B.C. That any appreciable number of Toreva-blocks were formed at that time may be doubted, both on the grounds of the relatively short duration of that episode and of the apparent antiquity of the slides as evidenced by their stage of dissection.

[12] T. Armijo (Indian trader), oral communication.

[13] H. H. Robinson, "The San Francisco Volcanic Field," *U.S. Geol. Surv. Prof. Paper 76* (1913).

[14] C. E. P. Brooks, *Climate through the Ages* (1928), p. 393.

SNOWSLIDE STRIATIONS

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ABSTRACT

Snow, sliding in considerable mass down steeply inclined stratification plane surfaces of limestone, has produced, with the aid of rock tools, striations identical with those due to glacial action. The boulders which caused the marks were found in place at the end of the striations.

INTRODUCTION

Striations and groovings, in practically every characteristic aspect exact replicas of those produced by glacial scour, occur on rock surfaces immediately adjacent to the fronts of small glaciers in Glacier National Park. An extraordinary feature of the development is the retention, at the end of a groove, of the rock tool which did the engraving, a fact which makes inescapable the conclusion that one boulder, in a single traverse over the course, produced the groove. On first examination the phenomenon could be accounted a perfect confirmation of orthodox inferences in regard to the processes of glacial abrasion. While such inferences may be warranted, the grooves here described are probably not due to glacial action. But they do apparently afford a striking demonstration of the facility with which processes akin to glacial action can effect such grooving. If the conditions under which it was formed were not known, a similar development encountered away from the associations present at this site would almost certainly be interpreted as of glacial origin.

DESCRIPTION OF THE SITE AND THE GROOVES

Near the eastern base of Mount Jackson in Glacier National Park the top surface of a massive bed of Siyeh limestone dipping outward 20°–25° constitutes the mountain slope over a considerable area. On this surface, superposed on older glacial striae, is a set of similar but less numerous and clearly younger markings. These consist of straight grooves which trend in the direction of dip (down the slope).

At the lower termination of such a groove is found a boulder which apparently is the tool that did the grooving. These boulders are limestone of the same formation as the underlying rock and range in size from small fragments several cubic inches in volume to boulders roughly 8 inches on a side. The sites where some of them were pulled from the bedrock can be identified. Others were brought down to the grooved surface from morainic deposits or from bedrock higher up the slope.

As is commonly true of glaciated rock surfaces, the one on which these boulders occur exhibits a more or less corrugated appearance due to the abundance of glacial grooves and striae present. Here these range in size from very small scratches to grooves several inches deep and up to nearly a foot in width. The entire surface, including the portion within those grooves which are certainly of glacial origin, is weathered to the extent that the rock is somewhat softened and has a uniform buff color. The fresh rock is bluish gray. The maximum thickness of the weathered shell probably does not exceed $\frac{1}{8}$ inch and for the most part measures about $\frac{1}{16}$ inch.

The superposed striae extend parallel to the older grooves; some of them partially coincide with the courses of the older grooves. But the superposed striae appear quite fresh. Weathering has not smoothed off their edges and the surface within them is lighter in color than the adjacent limestone (Fig. 1). An identical effect is produced when the limestone is scratched with a knife point. The unweathered grooves range from a mere trace to more than an inch in width and have depths up to $\frac{1}{4}$ inch. In nearly every instance the grooves are most prominent, particularly in width, near the boulder lodged at their end. The increased width indicates that the cutting points of the boulders were blunted while functioning as the abrading tools. Examination showed such inference to be correct in the case of those at the ends of grooves which could be traced for a distance of 35 feet or more. Smaller boulders, found to be derived from the intersections of joints on the rock surface only 10 or 15 feet distant, had uniformly sharp edges. But the grooves these sharp boulders made were deeper than those made by the rounded boulders. All the superposed grooves were cut mainly in the weathered portion of the underlying limestone. However, where the courses cross joints or

irregularities in the surface the grooves extend down into the blue unaltered rock.

FIG. 1.—Several boulders on the partly weathered dip slope of Siyeh limestone at the Siksikaikwan glacier site, August 24, 1936. The largest boulder seen in the picture is roughly 8×6×6 inches. The view looks down the dip to the morainic ridge.

This area is one from which Blackfeet glacier has rather recently withdrawn. The recession of this glacier has been rapid,[1] although

[1] G. C. Ruhle, "Measurements on Glacier Recession in Glacier National Park. Year 1936," *Report of Park Naturalist*. Mimeographed, obtainable from National Park Service, Glacier National Park.

during the period of accurate measurements (1932–36, inclusive) its retreat has amounted to only slightly more than 10 feet annually. In view, however, of the amount of weathering which the limestone surface has undergone and the amount and kinds of vegetation on the nearby morainic deposits, it seems hardly possible that the area was ice-covered at any time during the last fifty years. It also appears that the ice which had extended thus far at an earlier date had a thickness not exceeding 50 feet. At present the west lobe of Blackfeet[2] glacier, known as Siksikaikwan glacier,[3] terminates about half a mile from this site. It rests on the surface of limestone beds dipping in the same direction and at the same angle as the surface under discussion and flows down the dip of these beds. This lobe of the glacier appears not to have developed a cirque with a floor lower than its outlet because of the steepness of the dip of the beds over which it moves. Accordingly the glacier ice does not exceed 25 feet in thickness at points approximately $\frac{1}{4}$ mile back from its front. The ice which covered the grooved limestone surface when the glacier was considerably larger than at present must have been similarly thin.

The rate of movement of Siksikaikwan glacier is 45 feet in a year according to measurements for the years 1934 and 1935 made by Dr. Ruhle.

ORIGIN OF THE GROOVES

The two possible origins of the superposed grooves are (1) glacial action and (2) snowslide action.

Glacial origin.—On the basis of the mechanics involved it would seem that a very considerable thickness of glacial ice would be required to supply enough pressure to produce striae with depths of a quarter of an inch or more in a single traverse. But the situation is such as to make the recent presence of thick glacial ice inconceivable. On the other hand, the striking similarity of the superposed grooves to striae of unquestioned glacial origin would ordinarily warrant assigning them to the same agency. Moreover, the superposed grooves extend parallel to the older ones which are undoubtedly of

[2] On the Glacier National Park and Chief Mountain, Montana topographic sheets of the U.S. Geol. Surv., Blackfeet glacier is incorrectly labeled Blackfoot glacier.

[3] *Op. cit.*

glacial origin, and they are parallel to the direction of flow that a glacier covering the area would probably, though not necessarily, follow.

It is, however, exceedingly unlikely that boulders as small as those found here would have remained fifty years or more at the exact spot on which a glacier left them. During most of the period of the year (usually less than two months) that the surface on which the boulders rest is not snow-covered it is subject to the action of water from melting snow higher up the slope. The steepness of the slope leads one to infer that snowslides must be frequent, or at least that snow-masses must shift enough to have displaced the smaller stones. The smooth, steeply dipping surface forms a natural "sliding board." Accordingly the fact that the very small stones in August, 1936, were in many instances exactly in place at the lower ends of the grooves which they undoubtedly had produced makes their glacial deposition most improbable.

The inference that the steep outward dip of the formations promotes snowsliding and, incidentally, accounts also for the failure of the Blackfeet glacier to excavate a cirque basin (Fig. 2) is supported by the observations of Flückiger[4] who asserts that such surfaces are the only type of structure which can inhibit glacial erosion and promote the sliding of glacial ice masses. Flückiger (p. 19) cites an ice avalanche of the Altels glacier of the Bernese Oberland on September 11, 1895. A portion of the glacier resting on a stratification plane inclined 30° broke loose and plunged down to the Spital Meadow along the Gemmi path. The exposed rock surface, Flückiger says, did not have characteristic glacier modeling. On page 47 he returns to this topic as follows:

> Analysis of the glacial action at the Altels and Rosenlaui glaciers makes it evident that flowing ice has minimum adhesive and erosive effectiveness when moving over the stratification plane surfaces of steeply inclined formations. If it does excavate a cirque basin in such a structure the process is one of ripping out plate after plate of the dipping beds.

The fresh appearance of the superposed grooves is further evidence against a glacial origin. The Siyeh limestone weathers so

[4] Otto Flückiger, "Glaziale Felsformen," *Petermanns Mitteilungen, Ergänzungsheft*, No. 218 (1934), pp. 19 and 47.

rapidly that fresh surfaces would become discolored in a comparatively few years. But the smallest of these scratches appears as fresh as though it had just been made.

Snowslide origin.—As previously stated, the superposed grooves have been cut mainly in the partly weathered portion of the rock

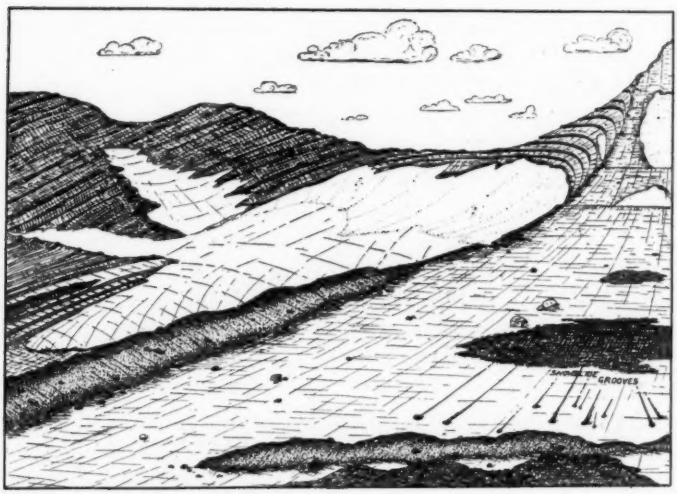

FIG. 2.—Idealized sketch showing relation of glacier, moraines, and snowslide grooves to the dip-slope surface. The grooves of most of the boulders can be traced upslope a distance of about 40 feet to the point where the rock surface meets vegetation-covered material beyond which bedrock again appears and continues unbroken, except for scattered thin patches of loose material, to the main mass of Mount Jackson where the dip, and thus the slope, appreciably steepen. The latter place is the site of snow accumulations which feed the slides.

surface. Less pressure would therefore be required to produce them than on fresh rock. Although parallel to the older grooves of undoubted glacial origin, both sets trend down the slope, a direction which snowslides would necessarily follow. Glacial striations examined adjacent to the ice-fronts of Blackfeet, Sperry, Sexton, and other glaciers on surfaces which the ice is known to have covered not longer than five years ago do not appear so fresh as the superposed grooves at the Siksikaikwan site. The recent glacial striations are

distinct but the surfaces within them do not have the "scratched" appearance which makes the others seem so perfectly fresh.

At Sperry glacier a similar but less impressive development of the same phenomenon was noted. In front of this glacier one side of a trough or small valley down which the ice had once moved is covered with glacial grooves and striae. At right angles to them other scratches or faint grooves appear. At the lower ends of the secondary striations boulders, the tools which produced the scratches, are present as in the case of the Blackfeet glacier site. However, these Sperry glacier striae were only found near the bottom of the glacial trough and in all cases are short, the longest probably being not more than 20 feet in length. But even these small and favorably located striae may not confidently be ascribed to glacial action because the rock surface on which they occur has been free of an ice cover for at least ten years according to people who have been in the region that length of time; and the slope on which the boulders rest is steeper than that on which the grooves occur at Blackfeet glacier. Furthermore, the Sperry secondary striae also extend down-slope in the direction that snow would slide; and this direction is at right angles to the trend of the numerous larger glacial grooves which indicate the direction of the former ice movement. The surface here is argillite of the Grinnell formation and its hardness is greater than that of the Siyeh limestone, which may account for the comparatively slight development of the Sperry scratches.

At the Blackfeet site the sparseness, and hence the wide spacing, of the grooves indicates that they were made in a very brief period. Glaciated rock surfaces are usually ice-polished or else almost entirely covered with grooves and striae. As ice moves continuously across an area, silt, sand, and rock fragments are pushed over it unceasingly until polishing or such complete striation results. Here however, a very few boulders were employed (Fig. 3), a circumstance which indicates that a single snowslide in action perhaps only a few minutes or even only a few seconds was responsible.

Immediately beyond, down-slope from the grooved surface, a tightly compacted, vegetation-covered morainic deposit forms a low ridge (Fig. 2). This moraine is possibly 15 feet high and extends transversely to the slope, hence also to the trend of the grooves.

This ridge would serve as a partial check to the motion of a snow-slide from farther up the slope. On encountering the side of this

FIG. 3.—View looking down the dip at the same site as Figure 1, August 24, 1936. The boulder in the picture is the largest of all those seen. It is roughly 8 inches on a side, and its groove, at places $\frac{1}{8}$ inch or more deep, can be traced for 50 feet to the upper border of the immediate rock surface.

moraine the bottom masses of the sliding snow would have their motion abruptly checked. Such braking action might momentarily increase the pressure developed at the bottom of the snow mass and so explain the presence of more and larger grooves near the moraine

than on surfaces higher up the slope. Further, such retardation of the basal part would account for the presence of boulders so delicately lodged on a steep (25°) slope.

SUMMARY

The literature on striations and avalanches apparently contains no record of a development such as that described above.

The evidence presented indicates that the grooves in question owe their origin to a recent snowslide; one which probably occurred in the winter previous to August, 1936, when they were observed. It seems that there is no essential difference in the striations produced by the scouring erosion of both snowslides and glaciers. There is, however, a profound difference in the rapidity of the action. As those boulders which moved the greatest distance are less angular, it appears that rock-tools imbedded in the base of the snowslide are, as glacier pebbles seem also to be, subjected to rotation during transportation. Probably the velocity of motion[5] is the factor which makes a swiftly moving snowslide capable of producing, in a second or two, striations and grooves that a thick glacier would require a much longer time to engrave by its cumbersome flow.

[5] O. D. von Engeln, "Flood Erosion," *Preliminary List of Titles and Abstracts of Papers, Geol. Soc. Amer.* (1935), p. 36.

THE DYNAMIC METAMORPHISM OF A PEGMATITE

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ABSTRACT

A soda pegmatite occurs in Ontario, one part of which is bent, squeezed, and metamorphosed to a schist. Mineralogically the chief difference in the two rocks has resulted from an addition of chlorite. Additions of water, magnesia, and ferrous iron, and losses of alkalies, lime, alumina, and silica, are indicated by chemical anaslyses.

INTRODUCTION

A peculiar dike was sampled by F. F. Grout in 1934 north of Goudreau, Ontario. One part of the dike was still in its original state, while another part, clearly derived from the same original material, was thoroughly altered to schist. It was thought worth while to study the specimens in some detail both petrographically and chemically. The writer is grateful for the assistance given by Professor Grout and Dr. R. B. Ellestad in this work.

LOCATION AND OCCURRENCE

The exposure mapped in Figure 1 is on a point on the east shore of Herman Lake about one-half mile from the north end of the lake. The pink pegmatite dike, several inches wide, strikes E.–W. with a vertical dip and intrudes greenstone country rock. It can be followed up the slope from the water's edge for a number of feet and then seems to fade out. Close inspection, however, shows it to be continuous, turning nearly 90° toward the south and narrowing down to a few inches with a 60° dip to the west. Numerous SW.–NE. faults cut across the dike, each offset portion on the southeast having moved progressively farther southwest. On following the pegmatite dike around the bend toward the southeast, it was found to become increasingly more schistose until, when completely around the bend and in the narrow portion of the dike, it was distinctly a schist, greenish gray in color. Here the dike so closely resembles the greenstone walls that anyone seeing only the sheared metamorphic portion would never suspect its pegmatitic origin.

PETROGRAPHIC NOTES

The pegmatite, where unaltered, has grains up to an inch or more across, necessitating a large number of chips, taken at regular intervals from the wide portion of the dike, for a representative

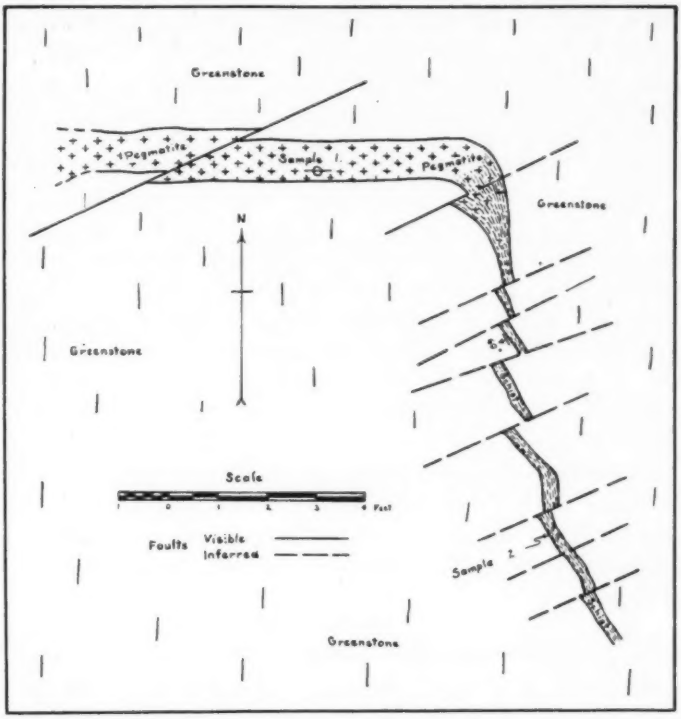

FIG. 1.—Map of a pegmatite dike on the east shore of Herman Lake, north of Goudreau, Ontario. (Mapped by F. F. Grout.)

sample. In the field the pegmatite shows pink feldspar with a little quartz and mafic material. A thin section made from a chip having a medium granitoid texture did not include the quartz, but did contain about two-thirds albite (index $\alpha' = 1.526$). There are minor amounts of muscovite, a light-colored epidote, and a small amount of accessory ilmenite, and secondary chlorite, limonite,

leucoxene, and a carbonate. Although the feldspar twins are bent and show strain shadows, the rock in this portion of the dike is very little metamorphosed. It is noteworthy that practically all the feldspar shows albite twinning in spite of its pink color.

The schistose part of the dike is too fine grained for field recognition of minerals. Thus a few chips were sufficient for an average sample. This rock weathers more rapidly than the unaltered pegmatite and is rather thickly coated with lichens. It has a dull brownish-green color with a slight luster on the cleavage surfaces and may have been slightly oxidized by weathering. Shearing and schistosity are much in evidence in thin sections. The grains which, in the unaltered pegmatite, are nearly all greater than 1 mm. in diameter are crushed to less than 0.1 mm. in the schistose part of the dike and most of them to less than 0.02 mm. In a large thin section three grains appear to be augen, left without much reduction in length, but the rest are apparently all thoroughly granulated. This change in texture is not accompanied by any very great change in mineralogical composition. The greater part of the rock is still composed of albite (index $\alpha' = 1.528$), but epidote, chlorite, and a little pyrite occur along shear planes. Chlorite is scattered throughout the section in oriented plates, constituting about 25 per cent of the schist and giving the rock its cleavage. The muscovite has almost entirely disappeared and does not seem to have formed sericite. Minor amounts of leucoxene, limonite, and a carbonate are present.

CHEMICAL DATA

Analyses of the two rocks establish the highly sodic character of the pegmatite (Table 1). Besides confirming the microscopic examination, they show the chemical changes that took place during the dynamic metamorphism. These are easily seen in the straight-line diagram, Figure 2. The low silica content in the pegmatite can perhaps be explained by the fact that nepheline-syenite outcrops within a half-mile to the north. The volatile matter found by ignition (in addition to the water, carbon dioxide, and sulphur) was probably in lichens which may have been in fractures and could not be removed. The lime in the unaltered dike was apparently in the epidote, as the feldspar seems to be pure albite. In the altered rock the feldspar is only slightly if at all changed.

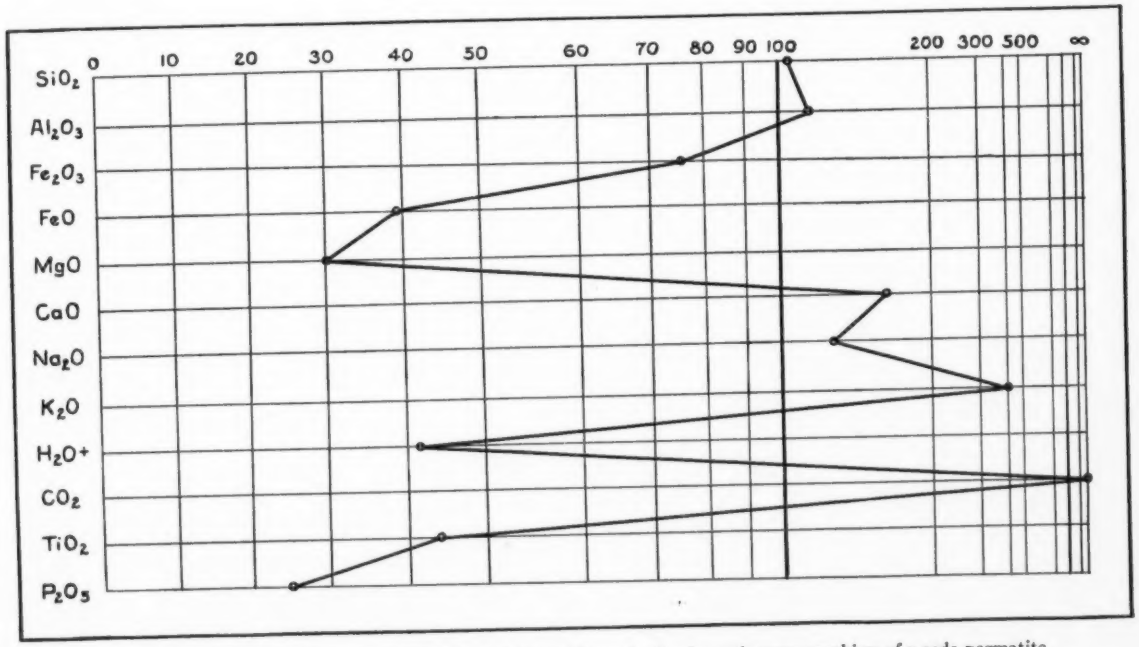

FIG. 2.—Straight-line diagram showing relative gains and losses in the dynamic metamorphism of a soda pegmatite

The two rocks are so nearly of the same specific gravity and porosity that the differences in the analyses indicate rather closely what has been added and what has been removed. However, the accurate data on the specific gravity and porosity have been taken

TABLE 1

ANALYSES OF A SODIC PEGMATITE AND ITS METAMORPHOSED PRODUCT (J. L. LINDNER, ANALYST)

	Percentage		1/2×100	Grams in 100 cc. of Rock*		Gains or Losses in Grams per 100 cc. Rock
	1	2		1	2	
SiO_2	63.48	62.29	102	167.40	160.61	−6.79
Al_2O_3	19.95	17.95	111	52.61	46.31	−6.30
Fe_2O_3	0.76	1.01	75	2.00	2.61	+0.61
FeO	1.51	3.89	39	3.98	10.04	+6.06
MgO	0.68	2.18	31	1.79	5.62	+3.83
CaO	2.04	1.35	151	5.38	3.48	−1.90
Na_2O	9.85	8.18	120	25.97	21.10	−4.87
K_2O	0.20	0.05	400	0.53	0.13	−0.40
H_2O+	0.77	1.86	41	2.03	4.80	+2.77
H_2O-	0.03	0.07	43	0.08	0.18	+0.10
CO_2	0.28	Trace	.....	0.74	Trace	−0.74
TiO_2	0.22	0.50	44	0.58	1.29	+0.71
P_2O_5	0.02	0.08	25	0.05	0.21	+0.16
S	n.d.	0.04	.....	n.d.	0.10	+0.10
MnO	0.05	0.07	71	0.13	0.18	+0.05
Volatile matter	0.09	0.28	32	0.24	0.72	+0.48
Total	99.93	99.80	.....	.....	.....	.....

* Percentage of constituent times "apparent" specific gravity.

1. Unaltered pegmatite from the east shore of Herman Lake, north of Goudreau, Ontario. A persodic pulaskase. Density $\frac{24.9^\circ}{4^\circ} = 2.679$. Apparent specific gravity = 2.637. Porosity = 1.56%.

2. Metamorphosed pegmatite from the east shore of Herman Lake, north of Goudreau, Ontario. A grenadose. Density $\frac{24.8^\circ}{4^\circ} = 2.697$. Apparent specific gravity = 2.580. Porosity = 4.32%.

into account in the calculations for the last three columns of Table 1. The large additions are water, magnesia, and ferrous iron, the latter probably all forming chlorite, which is several times more abundant in the schist than in the original dike. Since the greenstone of the walls is chloritic, it may be suspected that some material migrated from the wall during metamorphism, but the field and microscopic study gave no conclusive evidence of such migration. The minor additions include Fe_2O_3, P_2O_5, TiO_2, S, and MnO. The loss of soda

was 4.87 grams per hundred cc. Other significant losses were in lime, potash, alumina, and silica.

CLASSIFICATION

The extreme sodic character of the rocks lends interest to their classification. Under the C.I.P.W. system the pegmatite is a persodic pulaskase (I.5.2.5) for which no name has been suggested. Perhaps a locality name for this occurrence on Herman Lake might be acceptable. The schist is a grenadose (II.5.2.5). Under Johannsen's classification[1] the pegmatite would be an albitite (1 1 12 H). The schist would be classified as sodaclase-diorite (2 1 12 H). No albitite of exactly similar analysis was found in the rocks listed in Washington's "Chemical Analyses of Igneous Rocks."[2] The closest approach seems to be an albitite (I.5.1.5) which has, however, a lower lime content than the one in this discussion and falls into a different range in the C.I.P.W. classification.

Johannsen[3] lists an albitite from Australia having a very similar distribution of alkalies. However, the analysis given is very incomplete, so no exact comparison is possible.

[1] Albert Johannsen, *A Descriptive Petrography of the Igneous Rocks*, Vol. I (Chicago: University of Chicago Press, 1931), pp. 154–55.

[2] H. S. Washington, "Chemical Analyses of Igneous Rocks," *U.S. Geol. Surv. Prof. Paper 99* (1917), p. 285.

[3] Vol. III (1937), p. 141.

REVIEWS

Economic Geology of Mineral Deposits. By ERNEST R. LILLEY. New York: Henry Holt & Co., 1936. Pp. x+811; figs. 301. $5.00.

How the critical reader evaluates this interesting book depends very largely upon his understanding of the purpose motivating the author, as outlined in the Introduction, and upon his appreciation of that purpose. For this text is a distinct departure from the others which have appeared in recent years, and is scarcely to be judged by orthodox standards. It has little of the typical *Handbuch* or *Treatise* quality. If what is desired is an exhaustive treatment of the origin of mineral veins, or of the metamorphism of coal, other works are available. But none other, in the opinion of the reviewer, could be placed into the hands of what the author describes as the "serious-minded citizen" with any hope of appreciation for more than the scholarliness of the author. There is obviously need for a presentation of economic geology in a form that is useful to the student or "lay" reader, equipped with little background except the elements of geology and of world-trade. For the classroom it is desirable that such a work be organized as a text.

With minor omissions this book has admirably accomplished its objectives. Teachers in particular owe the author a vote of thanks. So also does the reader who wishes to understand that phase of geology, too generally omitted from current texts, which deals with the economic and industrial aspects of the subject. Such sections as those entitled "Technical Considerations," "The Economics of the Portland Cement Industry," and "Metallurgy of Zinc" give material of human significance and therefore of importance to the lay reader; in like manner they are significant to students interested in the subject for its cultural value or because of its bearing on a possible commercial career. Indeed, from this viewpoint the book may be described as a most effective piece of propaganda. Equally important, however, is the bearing which this same material, though perhaps not strictly geologic, may have upon the work of the practicing geologist. Yet production costs, the economic significance of various methods of treating ores, and the like are generally omitted from textbooks of economic geology or are presented in a purely statistical fashion, from which only the exceptional reader can derive the generalizations that are necessary to give them significance. The reviewer, for

example, in his courses in economic geology, has found it necessary to supplement strongly the material in one of the best-prepared texts in economic geology by means of special lectures on mineral economics and on exploitation factors. Judging from casual conversations, this practice seems to be general.

Despite the rather far-reaching statements which a book of this essentially elementary nature is forced to present, it is refreshing to note how modern is the viewpoint and information expressed in its pages. Thus, in the fifteen-page section on the formation of mineral deposits in general, the footnotes cite articles dated from 1924 to 1934. In this section, moreover, the reader is not bogged down with isolated facts. Generalizations are sought and made but good judgment prevails.

There are several lesser criticisms that might be made. The author fails at times to exploit in the text the illustrative value of the excellent figures that he has furnished. A place-name index would be highly useful to the student. Emphasis on the importance of potash, nitrogen sources, and phosphate as prime ingredients of fertilizers might be greater. The question of reserves of each raw mineral might have been more generally stressed.

But when all that is said, the book remains outstanding, especially in its skilful treatment of the economic aspects of mining geology. That this treatment has been incorporated without sacrifice of theoretical considerations, yet in a readable and attractive style, is a genuine tribute to the author.

CHARLES H. BEHRE, JR.

Grundzüge der Geologie und Lagerstättenkunde Chiles. By JUAN BRÜGGEN. Leipzig: Max Weg, 1934. Pp. 302; figs. 70; pls. 3.

The book represents a marked improvement on earlier monographs covering Chile and adjacent regions of South America. It is not too detailed for the novice, yet seems to face honestly the problems as yet unsolved by field investigators. Justifiable generalizations seem to be tentatively held. This balanced viewpoint is perhaps to be anticipated from a permanent resident like Dr. Brüggen, who is professor of geology at the University of Chile, Santiago.

The work begins with an outline of the major orographic and physiographic features of Chile. Successive sections deal with the following: the pre-Tertiary basement, the origin of the Andes after Cretaceous folding, the Andes of North Chile, the coastal features, Quaternary and Recent glaciation of the Andes, volcanism, seismology, and the mineral

deposits of Chile. Among the details of organization representing distinct assets are the general geographic map of Chile in outline, on which appear most of the points mentioned in the text. Minor defects are the absence of an index of illustrations and of the familiar *Ortsregister* (locality index), the possession of which is a point of superiority in most German regional descriptions.

Space forbids an extended review, but some of the general facts are significant, especially to students of North American orogeny. In the Andes the chief early folding, the date of which is not given, is along northwest trends, instead of northward, as in the "Andean" folding proper. In Professor Brüggen's eyes, there is strong evidence against any pre-Mesozoic crystalline mass parallel to and largely west of the present coast. The main folding came in the Middle Cretaceous, together with the intrusion of a huge granodiorite batholith traced from Cape Horn to Lat. 44° S., and with outliers as far north as Copiapo, Lat. 27° S.; to this batholith much of the ore deposition of Chile is linked.

The last great marine incursion took place in Eocene and Oligocene times. The present longitudinal valleys were developed by block faulting beginning in the Miocene and probably still in progress. Partial peneplanation intervened during these disturbances, permitting the marine and terrestrial Pliocene to lie generally on a flat surface. The subsequent history, sketched in broad lines, includes glaciation, and faulting so recent as to yield remarkable cut-off valleys. Apparently in the Andes, just as in the northern Rocky Mountains and more recently in Colorado, the picture is changing from simple folding with slight faulting to severe thrusting on flat planes.

Interesting and detailed descriptions are given of the glacial features in the higher mountains; of the deeply indented, fjordlike bays of Patagonia; and of the subcontinental ice sheet of the latter region. The sections devoted to the volcanism and seismology of Chile are equally scholarly and stimulating. So also is the discussion of the mineral deposits. In this, special attention is given to sodium nitrate, the guano deposits of the north Chilean islands, and the coal reserves. The latter are apparently quite limited in high-rank coals. Among the metalliferous deposits, the copper ores of the Blanco-Condes region, Potrerillos, Braden (Teniente), and Chuquicamata receive special attention.

In summary, this comprehensive, well-written account of Chilean geology must be highly welcome to foreign geologists.

CHARLES H. BEHRE, JR.

Interpretative Petrology of the Igneous Rocks. By HAROLD LATTIMORE ALLING. New York: McGraw-Hill Book Co., 1936. Pp. xv+353; figs. 48; pls. 11. $4.00.

As stated on the coverlet, the purpose of this book is

(1) to provide a chemical background for the study of igneous rocks; (2) to discuss the chemical nature of the common rock-making minerals, indicating their composition in terms of end molecules or minals, and the relation of the chemical composition to optical properties; and (3) to present impartially the disadvantages and advantages of the various theories supposed to account for the origin of igneous rocks.

The first five chapters on the principles of equilibria, solid solutions and isomorphism, polymorphism, and readjustment during crystallization meet the first objective in a very condensed manner. The second objective is attained in the next seven chapters, which deal with the important groups of rock-making minerals. This section, in which optical properties of minerals are diagrammed in conjunction with the thermal diagrams of the same systems, is perhaps the unique feature of the book and its most useful contribution. The author, who appropriately calls this portion "petrologic mineralogy," devotes nearly one-third of the entire volume to this field.

Excepting for a few transitional chapters on zoned and twinned crystals, the order of crystallization, and intergrowths, the remainder of the book is devoted to petrogenesis. The crystallization of magmas, the differentiation of magmas, assimilation, final consolidation and deuteric effects, and the origin of magmas and magmatic provinces are all dealt with in appropriate chapters. The author has achieved his third objective by his treatment of these controversial topics without dogma.

Two chapters, on "mode versus norm" and "grain size," of petrographic rather than petrologic nature, and a final chapter on "interpretative petrology" conclude the book.

Because much of the book is written in the first person, it is informal in style and quite readable. Occasional "asides" or parenthetical remarks also break the stiff formality characterizing all too many current texts. The author has the fault, however, of occasionally introducing terms before they have been defined (see "liquidus," "solidus," and "eutectic point" on p. 9 which are defined later).

While such topics as stoping, lit-par-lit injection, and magmatization are treated, the problem of how magmas rise is but partially covered. Many references are up to date, yet essentially no space is given to the concepts developed by Cloos, Sander, and contemporaries relating to the

manner of emplacement and spatial relations of intrusives, batholiths in particular. The word "batholith" does not appear in the Index and is mentioned casually only twice in the book. In fact, the whole subject of structural petrology is relegated to a couple of pages at the end of the volume, whereas garnet reaction rims merit a whole chapter. A discussion of the problem of the batholiths and the mechanics of intrusion would not seem out of place in an interpretative petrology.

On the whole, the book is well set up and illustrated. The writer knows of no other work in which one can find so many data on igneous rock-making minerals and systems as in this volume. For this reason alone petrographers will find the book valuable.

F. J. PETTIJOHN

Engineering Geology. By HEINRICH RIES and THOMAS L. WATSON. New York: John Wiley & Sons, 1936. Pp. vii+750; figs. 271. $5.00.

Ries and Watson's fifth revised edition, in which the arrangement of material and space allotted to the various topics is essentially unchanged, hardly needs a review.

The reviewer has always liked particularly the chapters on minerals and rocks, the simplified rock tables for field use, the chapter on dam and reservoir sites, and the appendix giving names and addresses of the directors of national and state geological surveys. The illustrations and maps serve their purpose admirably.

The reviewer regrets the lack of chapters on mining, petroleum production, and geophysical prospecting—subjects upon which he always lectures to his classes. Civil-engineering students are prone to demand the development of mathematical formulae rather than their statement, and such development might have been included in the text.

Although one may not agree with the arrangement (e.g., the reviewer prefers to consider historical geology before economic), the text is well written and adequate for most courses given to civil-engineering students. It still maintains the leading position among textbooks in its field and should continue to receive its deserved popularity.

H. W. STRALEY III

Principles of Structural Geology. By CHARLES MERRICK NEVIN. New York: John Wiley & Sons, 1936. Pp. xii+347; figs. 163. $3.50.

Following the precedent set in the first edition, Nevin discusses structural geology for the beginning student. A chapter summarizing fracturing and a section on the criteria for the recognition of top and bottom

of folded strata are introduced to that end, and the difficulties encountered by the beginner in petrofabric analysis are emphasized.

All the points specially featured five years ago have been retained: the treatment of Daubree's experiments, the stress laid upon vertical forces; the chapter devoted to the topographic expression of structure; the discussion of compaction, to which field the author has made notable original contributions. In addition, the reviewer commends the emphasis placed upon practical economic applications, structural geology as a three-dimensional study, the unlikelihood of folds transmitting stresses for great distances, and the non-rhythmic character of diastrophism.

The time-honored conception of a land mass extending beyond the North American Atlantic continental shelf in Paleozoic time is implied, without mention of the alternative hypothesis of a narrow land of high relief. The failure of the author to define some important terms used in the text illustrates a common failing among geologists. It is unfortunate that the text had to be written so hastily, as evidenced by the frequent use of the indicative mode in place of the subjunctive, the occasional use of comparative adverbs where there is no comparison, and too frequent use of expressions of doubt or hesitancy, such as "more or less."

The author is to be commended for the inclusion of the chapter by E. B. Mayo on "Structures Associated with Igneous Intrusions." This chapter is particularly well adapted to the needs of beginning students for whom a lengthy discussion of the mode of emplacement and theories of origin of igneous forms would be out of place.

H. W. Straley III

Géologie stratigraphique (deuxième édition, entièrement refondue). By M. Gignoux. Paris: Masson & Cie, Editeurs, Libraires de l'Académie de Médecine, 1936. Pp. 710; figs. 145. Fr. 95.

"Thus, leaving to Pluto the obscure depths of the terrestrial crust, domain of the Petrographers, where resounds the rude rhythm of the hammers of the Niebelungen, it is Neptune who has ruled over our Stratigraphy."

This translated quotation from the closing paragraphs of a work whose every chapter reflects the love of the author for stratigraphy, traditionally a dull branch of the earth sciences, indicates perhaps the basis of the enthusiasm which M. Gignoux has written into every chapter. The study of formations, whose fossil facies delimit zones representative of ancient marine geographies, seems to give rise to feelings in this stratigrapher akin to the excitement of sailor explorers, and his fervor has made for

far more interesting reading than usually confronts the student of the records of changing seas.

The author of *Géologie stratigraphique* has succeeded in giving a simple, accurate picture of the general and regional stratigraphy of Europe. An excellent Index makes the contents of this rather large work readily accessible to reference and valuable in correlating the stratigraphy of other parts of the world with the European sections. A Bibliography of the principal publications of the last ten or twenty years, relating to European stratigraphy, increases its value as a basis for more intensive regional work. M. Gignoux includes brief accounts of those principles of sedimentology, structural geology, and physiography essential for the understanding of stratigraphy, introducing at illustrative points questions of eustatic adjustment, migration of faunas, and contemporaneity of similar; cycles on different continents.

The general plan of the first edition (1926) is retained, but the work is lengthened by the inclusion of fuller reports on the Paleozoic of central and eastern Europe and the Miocene and Pliocene of eastern Europe. The studies of the last ten years have permitted a new treatment of the stratigraphy of northern Africa. The chapter on the history of the "continent of Gondwana" has been synthesized to present clearly the author's concept. The final chapter on the Quaternary has been entirely re-written and greatly modified. Twenty-one figures have been added in the second edition; the original 560 pages have been increased to 684 pages of text in the present type, equivalent to 800 pages in the former type.

JEAN GRACE

Our Natural Resources and Their Conservation. By A. E. PARKINS and J. R. WHITAKER. New York: John Wiley & Sons, Inc., 1936. Pp. x+650, figs. 129. $4.00.

Is the general subject of our natural resources so innately interesting; or is it that the twenty-two individual authors who have written the twenty-three chapters of this book have contrived, almost without exception, to lend, in discussing each phase of conservation, a real fascination to their special topics?

When H. H. Bennett discusses "Soil Erosion and Its Prevention," when O. E. Baker writes on "The Agricultural Prospect," when J. Russell Smith contributes a chapter on tree crops, when Helen M. Strong analyzes the relations of industry to conservation ("Conservation of Natural Resources and the Manufacturing Industry"), and when Ellsworth Huntington treats of "The Conservation of Man," it is to be expected that the

book containing such a symposium should be well worth reading; one is not disappointed. Although experts and acknowledged authorities in special fields do not always write readable essays on their subjects (and, indeed, V. E. Shelford, covering the grassland problems and those of wild life, and Ralph H. Brown, on the arid and semiarid lands, have not reflected their pre-eminence in their special works of conservation in the articles which they have written), in general no complaint can be made of the style of presentation of any of these chapters. But not all the good articles, or yet the best, have been written by the most famous conservation scientists. Louis Wolfanger has given, in a comparatively short chapter, a clearly explained classification of the soils of the United States which any geologist might do well to read, and even study, whether or no he has any particular interest in conservation. The senior editor, A. E. Parkins, although he has failed in many respects in editorship, has proved himself a forceful author in "Our Waterways and Their Utilization," perhaps the most skilfully written chapter in the book. W. W. Atwood and Stephen S. Visher certainly deserve credit for work well done in their respective chapters on the history of conservation in America and on the history of the disposal of the public lands of the United States.

Perhaps there is duplication, which might have been eliminated by a stricter editorial policy; certainly the editors could have made the book valuable as a source book as well as a textbook if they had documented it more systematically and accurately and included an adequate bibliography. The individual authors have been variously conscientious in these matters. The work is uneven in quality, reflecting in part an unevenness in integration and extent of progress in the various fields, but also reflecting an imperfect choice of contributors. Geologists will be disappointed that the sections on the conservation of mineral and mineral-fuel resources are probably the poorest of the book. On the other hand, they will be consoled to find the erosional and depositional problems of Part II to constitute the most complete single division of the book.

The co-operative authors have agreed to devote the royalties from the sale of this book to the Association of American Geographers and to the National Council of Geography Teachers.

JEAN GRACE

Environment and Nation. By GRIFFITH TAYLOR. Chicago: University of Chicago Press, 1936. Pp. 571; figs. 147; tables 38. $4.00.

Intending this work as a contribution to the attainment of world-peace, Griffith Taylor attempts to further a general understanding of the

ecological factors of present-day European populations, and, through a historical and anthropological approach, to induce a better understanding of these populations themselves. It is a work on the borderline between geography and history, according to the author. Yet it might almost as readily be said to be a work on the borderline between anthropology and geography, or an integrated anthropology and history of the European nations. Perhaps it is only an extension of history in the difficult modern school—a story of peoples rather than of outstanding events and figures. At any rate, it is a tremendous compilation of knowledge.

To the geologist this essay in the social sciences will have more value for its thorough grounding in the geology of the continent which the author elected to study. For environment is aptly considered in geologic terms. Is the geological world aware of its possession of a unique technique of representation of facts? Mr. Taylor feels that block diagrams may be adapted to showing other things than folded strata; barbarian migrations and changing boundaries of empires are equally well indicated by a geologic technique. "Inliers" may apply to races, cultures, and languages as well as rocks.

Ambitious and stimulating, perhaps not altogether accurate, is it a favorable or an unfavorable comment that it should be reported as another unorthodox and individualistic product of a scientist who has provoked much controversy in several fields of science?

JEAN GRACE

Amerikanische Landschaft. Edited by ERICH VON DRYGALSKI. "Ozarkland," by RUDOLF SCHOTTENLOHER; "Kanadische Prärie," by MAX EICHMEIER; "Florida," by PETER BERGER; "Jamaica," by A. WILHELM KUCHLER; and "Seattle," by HOMER L. SEEGER. Berlin: Walter de Gruyter & Co., 1936. Pp. 532; figs. 100; correlation charts, 1.

One is at a loss to understand just why the Ozark land, the Canadian prairies, Florida, Jamaica, and Seattle should have been thought to compose the American landscape. Nevertheless, if not as a geographic description of America, then as a compilation of five excellent regional studies in America one must welcome this work of five of Erich von Drygalski's latest students. Throughout the work, but most notably in the essays on Jamaica, Florida, and the Ozark hills, there is a geologic emphasis to the geographic discussions, while the painstaking bibliographies which follow each article refer the reader directly to the most authoritative geologic studies of the area as well as to the geographic treatises.

American readers will be pleased that the German publishers have so attractively printed and bound a work of such interest and value.

JEAN GRACE

Gulf Coast Oil Fields: A Symposium on the Gulf Coast Cenozoic. By fifty-two authors; edited by DONALD C. BARTON and GEORGE SAWTELLE. Tulsa: American Association of Petroleum Geologists, 1936. Pp. xxii+1070; figs. 292; pls. 19. $4.00.

The contents of this volume, except for the seven-page Foreword, the six-page description of the Frontispiece (aerial photo-mosaic of Barbers Hill), and the twenty-page Index, comprise forty-four papers reprinted from the *Bulletin of the American Association of Petroleum Geologists*. All but two of these are from the 1933–36 volumes. They are arranged under three headings: "General and Theoretical" (14 papers), "Stratigraphy" (10 papers), and "Descriptions of Oil Fields" (20 papers). They deal with coastal Texas and Louisiana except for two on Mississippi and one on northeastern Mexico under the second heading, and one on an interior Texas salt stock under the third heading. A majority of them is very properly concerned with salt-core structure phenomena, but the volume is by no means limited to these. This collection will be very convenient for those working in or with the area, and, as the analogous reprint published ten years earlier (*Geology of Salt Dome Oil Fields*) is now quoted at $15, investors in these parlous times may think it a good "buy." Others will perhaps agree with the reviewer that the Association would be doing a task of much greater value to most all concerned were it to sponsor a series of works of similar size and title to be published for each petroliferous region of the United States, each to be a summary of conditions and their origins in the area concerned and not a series of relatively unrelated papers on individual pools.

D. JEROME FISHER

Internationaler Geologen und Mineralogen Kalender. By EDMUND BEYENBURG. (Published by Deutsche Geologische Gesellschaft.) Stuttgart, Germany: Ferdinand Enke, 1937. Pp. 588. Rm. 10 (less 25 per cent outside of Germany).

This book is a most useful world-directory of geologists and geological institutions. The first of the two main parts of the book is an address list of nine thousand to ten thousand geologists. The second part lists by cities, nations, and continents the state and federal geological surveys, college, and university geological departments; geological, mineralogical, and paleontologic museums; and societies, their series of

publications, the staff and rank of each member of the staff for the state and federal surveys, the staff and the rank and specialty of each member of the staff for the college and university geological departments, and the officers of the societies. Dr. Beyenburg seems to have taken many pains to insure high accuracy in his data. The reviewer has found previous editions a very handy book to have on his desk and believes that most geologists and geological institutions will find this a most useful reference book.

DONALD C. BARTON

The Structure of the Alps. By LEON W. COLLET. 2d ed. London: Edward Arnold & Co., 1935. Pp. 304; figs. 84; pls. 11. 20*s.* net.

This second edition of Collet's well-known work follows the earlier edition very closely for the most part but has been extended to include "The Alpine Range in the Western Mediterranean" (Part VI, pp. 255–90). In spite of this considerable broadening of scope, the volume has been lengthened by only fourteen pages. This has been due to a shortening of the bibliographies and of the descriptions of the Juras and to minor eliminations here and there.

The chief innovations in the treatment of the Alps proper are a discussion of "foundation folding" whose importance has recently been recognized, of Kober's views of Alpine synthesis which become increasingly significant as the scope of the volume is enlarged to include the Apennines and other ranges, and of the involution of the Jungfrau, clarified by recent researches.

Part VI consists of short, new chapters on the Apennines, Corsica, Sardinia, Elba, the Alpine chain of southern Spain, and the Balearic Islands.

R. T. C.

Great Earthquakes. By CHARLES DAVISON. London: Thomas Murby & Co., 1936. Pp. 286; figs. 97; pls. 12. 17*s.* 6*d.* net.

This volume describes eighteen of the greatest earthquakes of the last two centuries. These have been chosen partly for their magnitude and destructive effects but even more for the light which they throw on the nature and origin of great earthquakes. They are: Lisbon, 1755; Calabria, 1783; New Madrid, 1811–12; Cutch, 1819; Valparaiso, 1822 and 1906; Concepción, 1835; Owens Valley, 1872; Mino-Owari, 1891; Sanriku, 1896 and 1933; Assam, 1897; Alaska, 1899; California, 1906; Messina, 1908; Tango, 1927; Idu, 1930; and Hawke's Bay, 1931. The Tokyo earthquake of 1923 was not included in this series because the author had already devoted an entire volume to it.

While the method of treatment naturally varies somewhat with the individuality of each quake, the topics presented in an average chapter are: general setting, previous seismic activity in the region, investigation of the earthquake, loss of life and property, intensity and nature of the shock, seismic sea waves, dislocation of the crust, changes of land, landslips, aftershocks, and bibliography. Altogether these give in convenient form the essential facts known about each of these earthquakes. For a good descriptive text, a useful book of reference, and an authoritative treatment of the various phenomena involved, this work may be recommended to anyone interested in earthquakes.

R. T. C.

Geological Survey of British Guiana: 1934 Reports; General Geology. Pp. 76; maps 5. $3.00.

Geology and Gold Deposits of the Potaro: Geological Survey of British Guiana. Pp. 62; maps 1. 72c.

Geology and Gold Deposits of the Konawaruk. Geological Survey of British Guiana. Pp. 20. 12c. Georgetown: Demerara, 1936.

These three volumes, containing separate articles by various members of the government survey, are a well-integrated and uniformly well-written work of general interest.

The preliminary surveying of British Guiana has been conducted from the viewpoint of economic geology. It is with the particular intention of indicating the wisest course of development of the gold and diamond fields that the reports are submitted to the government and to the general public. Different theories of the origin of the gold are considered and, in order to throw light upon the genetic question, petrographic studies are made of the igneous rocks, and the historical geology of the region is worked out. From the preliminary field investigation it has not, however, proved feasible closely to correlate events in the geologic history of British Guiana within the world-wide geologic time scale. The methods and manner of concentration of the gold, which is recovered from various types of pay-dirts, are treated, and the conclusion is reached that there is no clear instance of a purely residual concentration of gold in the colony.

Recovery methods, ranging in British Guiana from primitive hand-workings to large-scale machinery production, and engineering and transportation problems receive consideration with respect to the individual fields.

JEAN GRACE

The Geology of the Iramba Plateau. By N. W. EADES, ("Short Paper No. 15, Tanganyika Geological Division.") Dar es Salaam: Department of Lands and Mines, Geological Division, Tanganyika Territory, 1936. Pp. 35; folded geol. map. *2s. 5d.*

Primarily investigated and written for the benefit of those interested in mining in the Iramba gold field, the economic geology in this short paper is substantiated by interesting petrographic studies, principally of igneous rocks.

JEAN GRACE

An Island Is Born. By NORAH D. STEARNS. Honolulu, Hawaii: Honolulu Star-Bulletin Company, Ltd., 1935. Pp. 115; figs. 55. $1.00.

Pele sang most lyrically for this geologist, wife of a geologist, whose words and humanly diagrammatic figures have succeeded in expressing the emotion of an earth drama. The island of Oahu has afforded an intimate picturing of the combat between the land-forming processes of vulcanism and the land-destroying processes of subaerial and marine erosion. Photographs, etchings, and diagram drawings of the sensational lava fountains, pools, and flows of now-erupting volcanos, and the vivid word descriptions of exciting moments of past volcanic events are more startling but not less beautiful than the work on the slower drama of erosional processes and changes of sea-level and the descriptions and photographs of the present physiography.

And yet—that it is a pioneer venture in a neglected side of geology, rather than that it possesses great innate worth, constitutes its chief recommendation.

JEAN GRACE

Lehrbuch der Geologie, Teil III: *Geologische Länderkunde* (*Regionale Geologie*). 7th ed. By F. X. SCHAFFER. Leipzig and Vienna: Franz Deuticke, 1937. Pp. 95; figs. 51.

The *Lehrbuch der Geologie* consists of three parts: General, Historical, and Regional Geology. The third part has been appearing since the first leaflet in 1931 as small pamphlets, each dealing with a region of peculiar interest. This, the seventh of the regional studies, deals with the Alps and includes, as have the previous works, a satisfactory geologic description, an abundance of diagrams and figures, and a Bibliography of the literature on the regional geology.

JEAN GRACE